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ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA:
AN ATLAS OF TEMPERATURE FREQUENCIES

by

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13. ABSTRACT

The twenty-six maps contained in this Atlas depict the distribution of temperature in mainland Southeast Asia (Thailand, Vietnam, Cambodia, Laos, Burma south of 25° N latitude, and the peninsular portion of Malaysia) during the warmest (April) and coldest (January) month of the year at levels of probability selected for their significance to research and development and to military planning. Temperature analyses for January and April have been prepared for the 5, 10, 90, and 95 percent frequency of temperature occurrence levels, also mean monthly temperature and absolute maximum temperature. Also shown on the maps are the areas of Southeast Asia subject to temperature conditions considered analogous to those experienced at two sites in the Canal Zone: Cristobal, representing the warm and wet Caribbean slopes, and Howard AFB representing the drier and hotter Pacific slopes.

The principal areas of Canal Zone temperature analogy in Southeast Asia during both January and April are confined to the southernmost or equatorial portions of the region. In January, practically all of the mainland (north of about 10 degrees north latitude) is too cool to be analogous to temperature conditions of the Canal Zone. In April, the warmest month in most of Southeast Asia, the area of analogy is much more far-reaching, and includes the moderately elevated uplands of the northern interior as well as many lowland areas. However, the densely populated interior lowlands of the Menam basin in Thailand and the Irrawaddy basin in Burma are too hot during April to be classified analogous.

FOREWORD

This report is the fourth to be completed by the Earth Sciences Laboratory under Project PROVOST (Priority Research Objective for Vietnam Operational Support). As one of the PROVOST series, the study is designed to develop information of special import to activities in Vietnam; as an Earth Sciences publication it is intended additionally as a contribution to the general fund of information available on the environment of Southeast Asia.

Maps of the type contained in this study should prove valuable for purposes of logistical planning for Southeast Asia and for research and development. The discerning user can retrieve several types of information from them, including levels of temperature exceeded 5, 10, 90, and 95% of the time; he can also arrive at reasonable judgments concerning the distributions of temperature at critical frequency levels. In addition, estimates can be made as to what areas of Southeast Asia have thermal stresses comparable to those experienced in the Canal Zone, an important consideration in assessing the degree of world applicability that may be attached to results of tests made at Army test stations in the Canal Zone.

Further work is needed on other aspects of temperature frequencies, such as the durations of critical temperature thresholds.

The Cartography in this report was compiled by Mr. John Griffin, under the supervision of Mr. Aubrey Greenwald, Chief of the Cartography Office, Earth Sciences Laboratory.

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ABSTRACT

The twenty-six maps contained in this Atlas depict the distribution of temperature in mainland Southeast Asia (Thailand, Vietnam, Cambodia, Laos, Burma south of 25° N latitude, and the peninsular portion of Malaysia) during the warmest (April) and coldest (January) months of the year at levels of probability selected for their significance to research and development and to military planning. Temperature analyses for January and April have been prepared for the 5, 10, 90, and 95 percent frequency of temperature occurrence levels, also mean monthly temperature and absolute maximum temperature. Also shown on the maps are the areas of Southeast Asia subject to temperature conditions considered analogous to those experienced at two sites in the Canal Zone: Cristobal, representing the warm and wet Caribbean slopes; and Howard AFB, representing the drier and hotter Pacific slopes.

The principal areas of Canal Zone temperature analogy in Southeast Asia during both January and April are confined to the southernmost or equatorial portions of the region. In January, practically all of the mainland (north of about 10 degrees north latitude) is too cool to be analogous to temperature conditions of the Canal Zone. In April, the warmest month in most of Southeast Asia, the area of analogy is much more far-reaching, and includes the moderately elevated uplands of the northern interior as well as many lowland areas. However, the densely populated interior lowlands of the Menam basin in Thailand and the Irrawaddy basin in Burma are too hot during April to be classified analogous.

ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA
AN ATLAS OF TEMPERATURE FREQUENCIES

1. Introduction

This atlas was designed for the two-fold purpose of showing the distribution of selected temperature frequencies in Southeast Asia and delineating those areas of the region where analogy with Canal Zone temperatures can be demonstrated at given levels of frequency. Its maps should aid materially in assessing the degree of world applicability attached to test results obtained at various environmental testing facilities operated by the Army in the Canal Zone. For purposes of this study, Southeast Asia is defined as Thailand, Vietnam (North and South), Cambodia, Laos, Burma (south of 25 degrees north latitude), and the peninsular portion of Malaysia.

The maps depict three aspects of temperature conditions during the months of January and April, which are respectively the coldest and warmest months on the average in the Canal Zone as well as in most of Southeast Asia. Included are maps that show levels of temperature met or exceeded 5, 10, 90, and 95 percent of the time. Other temperature elements mapped are mean monthly temperature (roughly the equivalent of temperatures met or exceeded 50% of the time) and absolute maximum temperature (an approximation of highest temperatures possible). An interval of 5 Fahrenheit degrees was used between isotherms on all maps. Completing the array of maps are one identifying the locations of meteorological stations and another showing the principal physiographic regions of Southeast Asia.

It is recognized that the elements and months selected for analysis permit the construction of maps for only a small percentage of the total number of month and element combinations possible. Nevertheless, when used in conjunction with other climatic studies of Southeast Asia, such as NLABS Technical Report ES-19, "Climatic Atlas of Southeast Asia" (39) this analysis provides a fairly complete description of the temperature regime of the study region.

In using the maps, the reader should bear in mind that reliability may be adversely affected in those places where data are sparse, and where map scale inhibits detailed analysis. These, together with other causes for possible reduced reliability are summarized briefly as follows:

- (1) The network of meteorological stations in Southeast Asia is thin, particularly in the mountainous districts.

(2) Statistics used in developing the maps were taken from a number of sources and are based on records of varying length. In general, short-term records of less than 3 years were ignored in making the analysis.

(3) Temperature analogy with Southeast Asia stations is fixed within limits 3 degrees both higher and lower than equivalent temperatures at the two Canal Zone sites. Thus, the requirements for analogy constitute a 6-degree Fahrenheit spread, a rather narrow range by world-wide standards, but suitable, nevertheless, for analysis of Southeast Asia where temperature stability at both diurnal and seasonal levels of consideration is much more evident than in regions of higher latitude.

(4) A large region (Southeast Asia) is compared to two small sites in the Canal Zone, one representing the drier Pacific slopes (Howard AFB), and the other the wetter Caribbean slopes (Cristobal). This translates into treatment of maps in pairs for all elements analyzed, with the two maps of each pair possessing identical isotherm patterns drawn to 5-degree Fahrenheit intervals for Southeast Asia. They differ only insofar as extent of analogy shown is concerned; such differences are contingent on temperature differences between Cristobal and Howard AFB. These two stations were selected as the key sites for determining analogy not merely for reasons of coastal position near either end of the canal itself but more importantly for the availability of weather records completely reflecting the climatic identity of each site. Also of foremost importance to the final selection was the availability at each site of hourly temperature tabulations, a type of record seldom included in published summaries and one without which this analysis could never have been conducted.

(5) For reasons associated with station siting, the temperatures taken at official weather stations, wherever located, need not be completely indicative of the degree of heating that takes place at nearby locations. Such may be the case, for example, with Cristobal, C.Z., a station located in a highly urbanized district where it is fully exposed to the warming effects of solar radiation. In the nearby forests, on the other hand, the shade provided by the overhead canopy of foliage has a dampening effect on temperature at all levels beneath the foliage deck. Striking evidence of this temperature disparity in the form of data and graphs is contained in recent progress reports on "Environmental Data Base for Regional Studies in the Humid Tropics", (41) a project currently being conducted by the U.S. Army Tropic Test Center, C.Z. It can be inferred therefrom that temperatures at standard height levels within tropical forests are from 2 to 4 degrees F lower on the average than corresponding temperatures at open sites outside the forests. This information can be construed to mean that the areal depictions of analogy entered on the maps contained in this study are indeed highly generalized patterns that may not fully represent the details of analogy at the local level of consideration.

(6) The frequency maps are drawn to values of temperature determined by read-out from hourly distribution curves constructed for 140 stations. Twenty-eight of these graphs are based on actual hourly temperature records for stations located in Thailand, Vietnam, and the Canal Zone. To fill the data void for large districts of Southeast Asia, the Spreen method (23) for empirically determining distributions of hourly temperatures was employed to develop curves for 112 additional stations. Such distributions are estimations, of course, and are subject to some degree of error. According to Spreen, however, the average error of the values produced for the stations used in developing the system is only 1.6 F°, and the bias is -0.1 F°. Actually, as applied to Southeast Asia, reliability should be even better than average test results indicate, since degree of error is below average in the tropical portion of the temperature scale (above 70°F). Temperatures below 10°F, the portion of the temperature scale where Spreen's method is least reliable, do not occur in Southeast Asia.

2. The Southeast Asia Temperature Regime: A Climatic Brief

Southeast Asia, generally speaking, has a typical tropical monsoon temperature regime with well-established cool and hot seasons. Temperature seasonality is determined largely by monsoonal control, with the winter or cool season corresponding to the northeast or dry monsoon prevailing from mid-October to mid-March, and the summer or warm-wet season corresponding to the southwest or rainy monsoon from mid-May to mid-September. Short transition periods in the spring and fall separate the two principal monsoon seasons.

When compared at the same elevations for the same period of time, temperatures are not greatly different in one sector of Southeast Asia than in another. Of the various causes for temperature modification in this part of the world, perhaps relief has the most discriminating effect on temperature behavior. The Annam Mountain Range, paralleling the Vietnamese coast on the east, the Burmese ranges on the west, the interior highlands of Burma, Thailand, and Laos on the north, and the peninsular ranges of Malaya on the south are particularly effective in this respect. Latitude, another controlling influence on temperature, leaves its mark on the thermal regime largely in the form of seasonal changes, but such variations are not great by temperate latitude standards and are confined chiefly to the northernmost districts of the region. Mention should be made also of distance from maritime influence as a control of temperature; this manifests itself in an increase of temperature variability, both diurnal and seasonal, with increasing distance inland from the coastal zone.

The winter season, the period of dominance by the northeast monsoon, is characterized by easterly or northeasterly airflow that brings relative

cool and dry air into the region. In this regard, the northernmost districts of Southeast Asia are most affected. Even in the north, however, winters are not extreme by most standards. During January, the coldest month, daytime temperatures usually reach into the high 60's or low 70's during the afternoon hours; at night, temperatures generally drop to the low 50's during the coolest period just before sunrise. In the south and peninsular portions of the region, temperatures are some 5 to 10 degrees higher, both day and night. Occasional frosts have been experienced in the upland districts of the north, but snowfall is unknown except perhaps at peak elevations in the north.

The summer season, or period of the southwest monsoon, is characterized by a flow of warm, moist, and unstable air into the region from the south or southwest, causing heavy local showers and thunderstorms in most sections. Temperatures are not exceptionally high on the average, ranging from the high 80's or low 90's during the hottest part of the day, to the low or high 70's during the coolest part of the night in most sections of Southeast Asia. Temperatures are somewhat lower in the mountains, decreasing as a rule at a rate of about 3 degrees Fahrenheit for every increase of 1,000 feet of elevation.

Seasonally, temperatures are highest during the spring transition period from mid-March to mid-May when skies are clear and the air dry. April, on the average, is the warmest month for most of the region; in the extreme northeast, however, the month of May averages out at a slightly higher level than April, a manifestation of the belated arrival of the summer monsoon in this sector. During the warmest month, daily maximum temperatures frequently exceed 100°F, and occasionally they exceed 110°F at interior localities well protected from maritime influences. Extremes above 100°F are seldom experienced at coastal sites.

3. The Map Series

a. Mean Monthly Temperature (Maps 3-6)

The sequence of mean monthly temperature maps is presented first in this Atlas because the normal temperature distributions they symbolize serve as a point of departure for discussing the series that follow. The sequence consists of four maps in all, two for January and two for April, with the maps of each pair drawn to reflect the areas of Southeast Asia that are subject to temperature conditions considered analogous to those at Cristobal, representing the wet Caribbean slopes of the Canal Zone in the one case, and those at Howard AFB, representing the drier Pacific slopes in the other.

The January maps of mean monthly temperature (Maps 3 and 4) illustrate the influence of latitude on temperature distribution as well as any maps in the series. In the southerly latitudes of peninsular Thailand and

Malaya, for example, temperatures are fairly uniform, averaging about 80°F at lowland sites. North of 10° North latitude a slight but steady decrease of temperature with increasing latitude becomes apparent. By 20° North latitude the decline amounts to about 10 F° on the average at elevations below 1,000 feet MSL. In the upland expanses of the northern interior, however, the influence of latitude is compounded by the effects of elevation in a way to further exaggerate mean temperature differences between southern and northern localities. This difference amounts to 15 F° to 20 F° on the average when comparing southern lowlands with northern uplands, and is even greater if crest elevations are considered.

The areas of Canal Zone analogy for mean January temperatures in Southeast Asia are shown for Cristobal on Map 3, and for Howard AFB on Map 4. The two maps are not greatly different with respect to the extent of analogous area delineated. On both maps, the analogous areas are confined to the lower latitudes of the region, involving, for the most part, the lowland areas of southern Thailand, southern Burma, the southernmost extremities of South Vietnam and the Malayan Peninsula. The small differences in the areas of analogy depicted on the maps are attributable to a difference of only 2 degrees between mean monthly temperatures given for the two Canal Zone sites. In the case of Cristobal, the representative station for the wetter and somewhat cooler Caribbean side, the mean for January is 80°F; this compares with 82°F, the equivalent value for Howard AFB, the station representing the drier and slightly warmer Pacific side of the Canal Zone. The effect of latitude on average temperatures is quite apparent on the two January maps. In general, analogy is confined to the southern maritime districts, where, as in the Canal Zone, temperature seasonality is barely perceptible and January temperatures average significantly higher than in the interior portions of the mainland to the north.

In April, however, analogy with Canal Zone temperatures is far more widespread within Southeast Asia. Not only is analogy maintained in the maritime equatorial districts of the south, but it establishes itself in the north as well, as temperatures rise to their climax in April. Map 5 shows the extent of analogy for the average temperatures at Cristobal, and Map 6 that for the average at Howard AFB. Since there is only 1 degree F difference between the two values given, and that in favor of the higher 83°F mean for Howard AFB, there is only a slight increase in the area of analogy outlined on Map 4, drawn to the Howard AFB mean. It is interesting to note that the low-lying interior basins of mainland Burma and Thailand are too hot for analogy with Canal Zone temperatures. This, of course, is associated with the springtime maximum of temperature characterizing the region in general and exemplified best in the Menam River basin of Thailand and the Irrawaddy River basin of Burma.

b.. Absolute Maximum Temperature (Maps 7-10)

An indication of how high temperatures actually have risen in various parts of Southeast Asia, together with a regionalized picture of what localities within the region have been subjected to absolute maximum temperatures in the range considered analogous to those experienced in the Canal Zone, is provided by Maps 7 through 10. In using the information portrayed on the set of absolute maximum temperature maps, however, one would be well-advised to proceed with caution. It should be remembered that extreme temperatures are as much a function of time as they are of meteorological conditions controlling the degree of heating for any specified moment at any one place. This means that the longer the period of record for temperature at any one station, the better the chance that a representative long-term extreme has been established. It follows, therefore, that the distribution of extremes shown on the maps could well be an underestimation, and that the extremes on record for the stations used in the analysis will likely be broken at some time in the future.

The areas of Canal Zone analogy in Southeast Asia for absolute maximum temperatures during January are shown for Cristobal on Map 7, and for Howard AFB on Map 8. Considering the distribution of extremes in Southeast Asia only, the maps show that the highest temperatures attainable in Southeast Asia during the coldest month are associated with the interior river basins of Burma and Thailand where extremes slightly in excess of 100°F have been recorded at a few sites. By and large, however, the extremes reached seldom exceed 90°F on the plateaus of the north, and 95°F in the equatorial maritime districts of the south. As for the extent of analogy, Map 7, drawn to an extreme of 90°F once experienced at Cristobal, reflects a less extensive area of analogy than does Map 8, drawn to an extreme of 94°F once experienced during January at Howard AFB.

The April maps of absolute maximum temperature (Maps 9 and 10) show the same basic, though somewhat higher valued, patterns of temperature distribution in Southeast Asia as the maps for mean monthly temperature. The interior basins of the Irrawaddy River in Burma and the Menam River of Thailand are the "hot spots" for the region in general, and the upland districts of the northern interior are the most extensive area of moderate temperatures. The restraint imposed on rising temperatures by maritime influences is demonstrated by the subdued temperatures adjacent to all coasts, both north and south. The highest temperature ever recorded anywhere within Southeast Asia is 114°F, reached during April at Mandalay, Burma. Areas of temperature analogy corresponding to the 95°F extreme recorded for Cristobal are shown on Map 9; analogy is associated mostly with the lowland areas of the Malayan peninsula, portions of the coastal zone in South Vietnam and Burma, and the lower slopes of the interior uplands at elevations roughly between 1,000 feet MSL to 3,000 feet MSL.

The analogous area shown for the Howard AFB extreme of 97°F (Map 10) is slightly more extensive, principally because the requirements for analogy in the mountainous sections of the interior are met at elevations about 500 feet lower than those on which Map 9 are based, thereby permitting inclusion of parts of the piedmont zone adjacent to the mountains within the analogous area.

c. Temperatures Equaled or Exceeded 5% of the Time (Maps 11-14)

Maps 11, 12, 13, and 14 depict the distribution of temperatures equaled or exceeded 5% of the time in Southeast Asia during January and April. Areas experiencing temperatures in the range of analogy determined for the stations of Cristobal and Howard AFB in the Canal Zone are indicated by special shading. The 5% level of temperature frequency is an indicator of the temperature level that will be exceeded 37 hours during 31-day months (January) and 36 hours during 30-day months (April). It has value in determining the degree of thermal stress to be considered in planning the logistics of clothing and equipment issue for Southeast Asia. The maps show the same basic patterns of temperature distribution as the mean monthly maps--that is, sharply contrasting thermal districts in the mountains, the impact of latitude in the northern districts during January, and a decided tendency for interior lowlands to heat more rapidly than surrounding districts.

The January maps (Maps 11 and 12) are notably different in the areas of analogy shown. Map 11, drawn to a base of 86°F for Cristobal, shows far less area of analogy than Map 12, drawn to reflect analogy with a 90°F temperature for Howard AFB. The higher temperature for Howard AFB permits analogy to be shown for most of the interior lowlands of Burma, Thailand, Laos, and Cambodia; when compared for temperature similarity with the lower Cristobal value, these same areas are too warm to be classified analogous.

The April maps (Maps 13 and 14) reflect a similar disparity in the distribution of analogy. The warmer Pacific slopes of the Canal Zone, as evidenced by a 5% temperature frequency level of 93°F at Howard AFB, find their terms for analogy met in rather far-reaching fashion at interior localities of Southeast Asia. The more moderate conditions of the Caribbean slopes of the Canal Zone, as represented by a 5% temperature frequency level of 87°F at Cristobal, find a more limited response to the requirements for analogy in an area that is confined largely to the uplands of the northern interior of Southeast Asia.

d. Temperatures Equaled or Exceeded 10% of the Time (Maps 15-18)

The distribution of temperatures equaled or exceeded 10% of the time in Southeast Asia, and the areas of the region subject to temperatures

considered analogous to those experienced 10% of the time at Cristobal and Howard AFB in the Canal Zone, are given for the months of January and April on Maps 15, 16, 17, and 18. The 10% level of temperature frequency is used in this study because it represents a level of temperature stress helpful to planners in determining equipment and clothing needs for Southeast Asia.

In January, the extent of the area of analogy in Southeast Asia for the 10% temperature frequency level of 88°F at Howard AFB (Map 16) is unusually widespread. The areas involved include the Kra plain of Thailand and the lowlands of the Malayan Peninsula in the south, and nearly all the interior and coastal lowlands at elevations from sea level to approximately 1,000 feet MSL of Burma, Thailand, Laos, and Cambodia in the central and north central districts of the region. Map 15, with analogy geared to a value of 85°F for Cristobal, also features extensive areas of analogy, but to a somewhat lesser degree than Map 16. Causes for the differences are attributable to the 3-degree temperature difference between values determined for Cristobal and Howard AFB, permitting the requirements for analogy to be met throughout the interior basins of mainland Southeast Asia in the case of the higher temperature for Howard AFB, but not for the lower temperature for Cristobal.

The April maps (Maps 17 and 18) contrast sharply with respect to areas of analogy shown. On Map 17, with analogy determined by the 85°F value for Cristobal, the areas of analogy are generally small and widely spaced, being restricted for the most part to the interior uplands and mountains at elevations between 1,000 and 3,000 MSL. In North Vietnam, however, analogy extends throughout the coastal lowlands to sea level, as it does in small pockets of the coastal districts of South Vietnam and the Malayan Peninsula. As for analogy based on the Howard AFB value of 91°F (Map 18) on the other hand, the area of analogy involved is greatly expanded, involving large portions of all coastal zones, a high percent of the interior basins, and all lower slopes of the interior uplands and mountains.

e. Temperatures Equaled or Exceeded 90% of the Time (Maps 19-22)

To test planners, design engineers, and/or military commanders concerned in any way with the total impact of temperature on men, equipment, or activities in Southeast Asia, the cool sector of the temperature cycle has important implications that rival those of the upper or warm portion of the temperature regime in certain respects. To help describe this lower portion of the temperature scale, the temperature level equaled or exceeded 90% of the time was selected for analysis and mapping in this study. Results are shown on Maps 19, 20, 21, and 22. These might be considered as cool-side counterparts to the 10% frequency maps (Maps 15-18) and have similar

relevance as environmental guidelines for purposes of designing or modifying military equipment or clothing.

The January maps (Maps 19 and 20) show that analogs of Canal Zone temperatures at the 90% frequency level have very little areal representation in Southeast Asia. Map 19, showing areas subject to temperature conditions considered analogous to the 90% temperature of 76°F for Cristobal, has hardly any analogous shading at all; analogy is confined to two small coastal districts, one on the east coast of the Malayan Peninsula and the other on the north shore of the Gulf of Thailand in the area adjoining the mouth of the Menam River. Map 20, drawn to a January value of 75°F for Howard AFB, reflects very little more area of analogy than Map 19. Enlargement of the coastal lowland areas of the Malayan Peninsula and Thailand, and the addition of a small coastal district in southern Cambodia constitute the chief differences in the areal picture of analogy. As reflected on both maps, the causes for the almost total lack of analogy in Southeast Asia during January is found in the fact that values for the 90% frequency of temperature occurrence level at both Cristobal and Howard AFB are higher than for Southeast Asia in general. By and large, except where already noted, the 90% temperatures in all lowland portions of Southeast Asia are on the average 5°F to 10°F lower than those of the Canal Zone.

In contrast with the January maps, the April maps (Maps 21 and 22) show widespread occurrence of analogy for the 90% level of temperature frequency. Both maps display nearly identical areal coverage for analogy, with Map 21 constructed to reflect analogy as determined by a base value of 78°F for Cristobal and Map 22 by a base value of 77°F for Howard AFB. The closeness of the values for the Canal Zone sites manifests itself in remarkably similar patterns of analogy in Southeast Asia, incorporating practically all lowland areas, both coastal and interior, and in certain districts, the lower slopes of mountain ranges.

f. Temperature Equaled or Exceeded 95% of the Time (Maps 23-26)

Like the maps of 90% temperature frequency, the maps showing the distribution of temperatures equaled or exceeded 95% of the time (Maps 23, 24, 25, and 26) help describe the distribution of temperatures in the cool or lower sector of the temperature spectrum for any particular site or area. Like Maps 19-22, they might be considered as cool-side counterparts to the 5% temperature maps, with associated uses in the field of equipment design and modification. They constitute, in fact, the means for areal portrayal of the lowest temperature level considered for mapping in this study, with results on the average delineating the 37 coolest hours of the month (in January), a fair representation of average temperatures during the coolest part of the night.

The distribution of Canal Zone analogy in Southeast Asia during January is shown for the 95% temperature frequency level on Maps 23 and 24. Both Map 23, delineating temperature analogy for Cristobal, and Map 24, delineating analogy for Howard AFB, are keyed to the same base value of 73°F for the 95% temperature level. As a consequence, the maps display identical patterns of analogy. The extent of analogy shown, however, is very limited, involving only the southern coastal margins of the Malayan Peninsula and small sections of the coastal zone in Thailand, Cambodia, and South Vietnam.

Temperature analogy during the month of April at the 95% level of frequency is shown for Cristobal on Map 25 and for Howard AFB on Map 26. The areas of analogy delineated on Map 26 (Howard AFB) are slightly larger than those of Map 25 (Cristobal) because of a small difference of 1°F between the base value of 77°F used in the case of Cristobal and 76°F in the case of Howard AFB. Both maps indicate that analogy is for the most part associated with the interior lowlands of the mainland, suggesting that nighttime temperatures during the warmest month in the so-called "hot spots" of Southeast Asia, such as the Menam River basin of Thailand, are very comparable to those experienced in the Canal Zone with respect to relief from the heat of the day.

4. Conclusions

Only in the equatorial portions of Southeast Asia (south of approximately 10 degrees North latitude) are the requirements for analogy with Canal Zone temperatures met during both the warmest and the coolest months of the year (April and January, respectively). Here, in the lowlands of the Malayan peninsula and the southern coastal zones of Burma, Thailand, Cambodia, and South Vietnam, the effects of low latitude and low elevation combine to stabilize the annual temperature regime within limits considered analogous to those characterizing the Canal Zone.

In January, most of mainland Southeast Asia (north of 10 degrees North latitude) is too cool for analogy with Canal Zone temperatures at practically all levels considered. The area of Southeast Asia classified as analogous is limited therefore to the southernmost extremities of the region, where seasonality of temperature is at a minimum. Insofar as mean temperatures during January are concerned, the averages for stations in equatorial Southeast Asia are remarkably uniform throughout the sector, fluctuating on the average within 2 or 3 degrees of the mean of 80°F for Cristobal, the station selected as representative of the wetter and somewhat cooler side of the Canal Zone. A January mean of 82°F for Howard AFB, in the drier and slightly warmer Pacific sector of the Canal Zone, finds a nearly equal response to the requirements for analogy in Southeast Asia, with the map showing a slightly enlarged area of analogy confined to the equatorial latitudes.

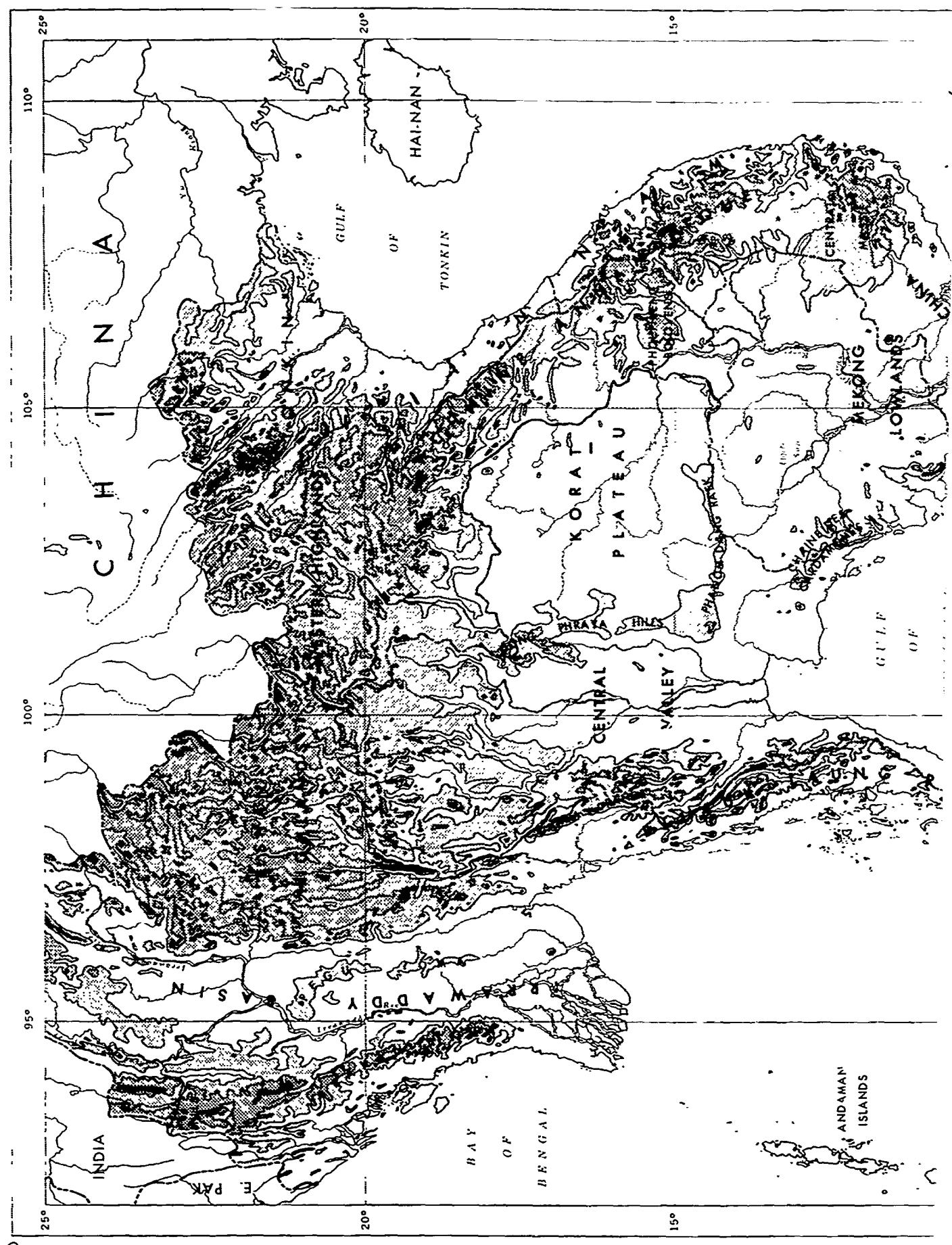
In April, however, analogy with Canal Zone temperatures is much more far-reaching in Southeast Asia, embracing not only the equatorial portions of the region, but including large sections to the north as well. It is interesting to note, however, that as the temperature rises to a maximum in April, the low-lying interior basins, such as the Menam River lowland of Thailand and the Irrawaddy River lowland of Burma, become too hot for analogy with Canal Zone temperatures. The April means for Cristobal and Howard AFB in the Canal Zone are 82°F and 83°F, respectively. This small difference in means resolves itself in nearly identical maps of analogy for Southeast Asia, both reflecting widespread areas of analogy. These involve both northern and southern districts, and the moderately elevated uplands as well as lowlands, the most notable exception being the interior basins already mentioned where much of the population is concentrated.

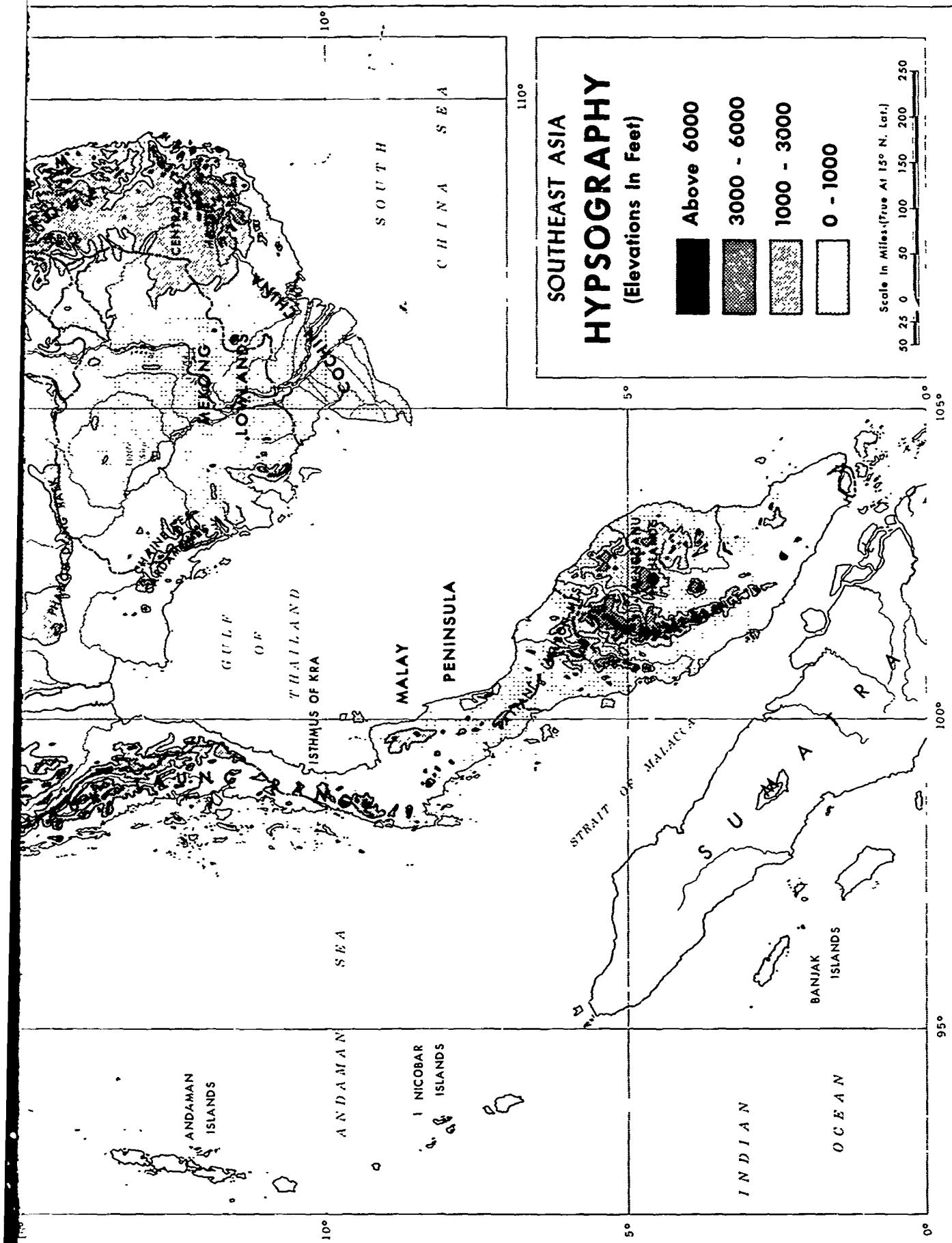
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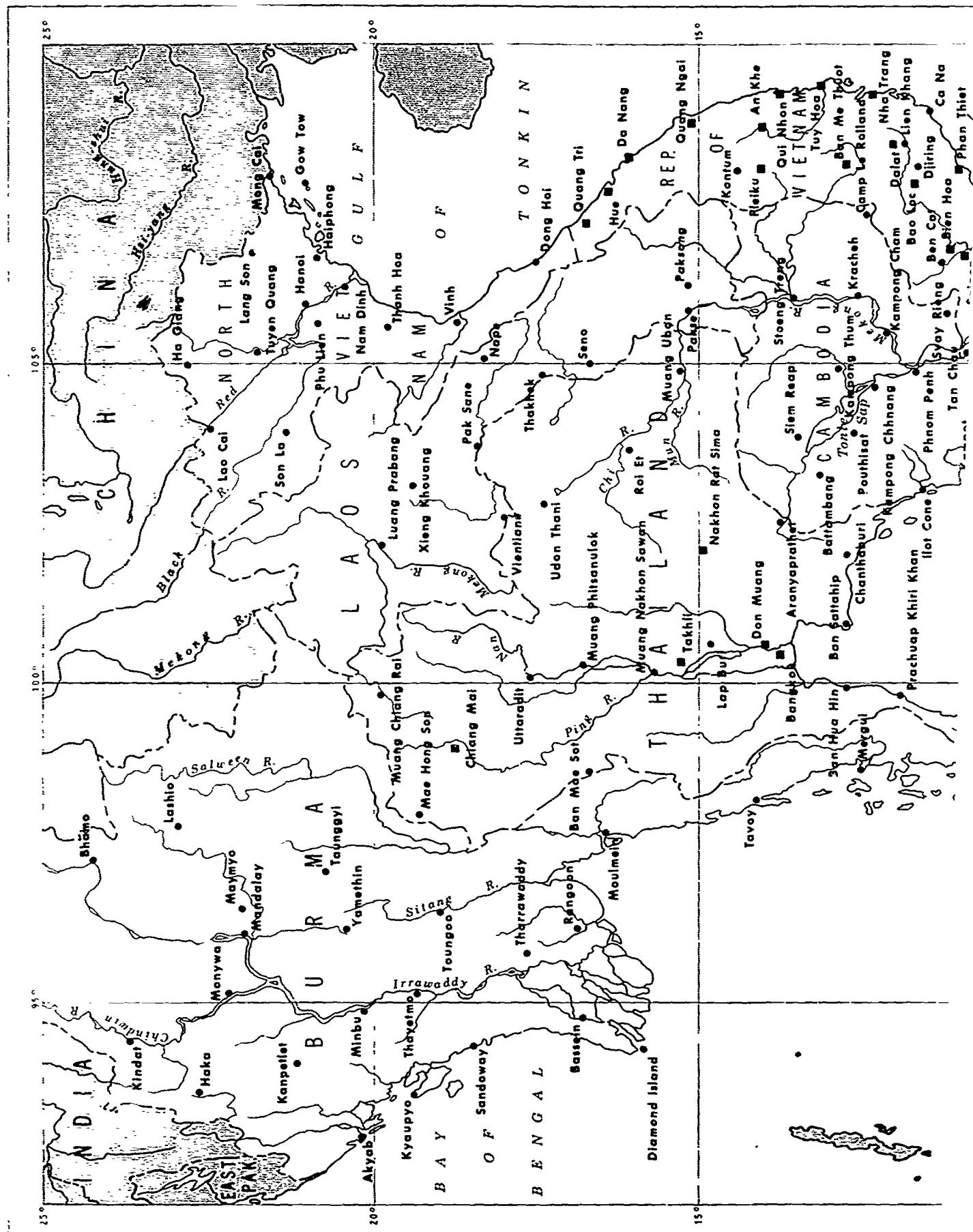
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MAP 1

ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA



MAP 2

SOUTHEAST ASIA STATION LOCATIONS

- Stations with records of hourly temperature frequencies available.
- Stations with only summarized climatic data available.

0 25 50 100
Statute Miles

950

1050

100

150

200

250

300

350

400

450

500

550

600

650

700

750

800

850

900

950

1000

1050

1100

1150

1200

1250

1300

1350

1400

1450

1500

1550

1600

1650

1700

1750

1800

1850

1900

1950

2000

2050

2100

2150

2200

2250

2300

2350

2400

2450

2500

2550

2600

2650

2700

2750

2800

2850

2900

2950

3000

3050

3100

3150

3200

3250

3300

3350

3400

3450

3500

3550

3600

3650

3700

3750

3800

3850

3900

3950

4000

4050

4100

4150

4200

4250

4300

4350

4400

4450

4500

4550

4600

4650

4700

4750

4800

4850

4900

4950

5000

5050

5100

5150

5200

5250

5300

5350

5400

5450

5500

5550

5600

5650

5700

5750

5800

5850

5900

5950

6000

6050

6100

6150

6200

6250

6300

6350

6400

6450

6500

6550

6600

6650

6700

6750

6800

6850

6900

6950

7000

7050

7100

7150

7200

7250

7300

7350

7400

7450

7500

7550

7600

7650

7700

7750

7800

7850

7900

7950

8000

8050

8100

8150

8150

8200

8250

8300

8350

8400

8450

8500

8550

8600

8650

8700

8750

8800

8850

8900

8950

9000

9050

9100

9150

9200

9250

9300

9350

9400

9450

9500

9550

9600

9650

9700

9750

9800

9850

9900

9950

10000

10050

10100

10150

10200

10250

10300

10350

10400

10450

10500

10550

10600

10650

10700

10750

10800

10850

10900

10950

11000

11050

11100

11150

11200

11250

11300

11350

11400

11450

11500

11550

11600

11650

11700

11750

11800

11850

11900

11950

12000

12050

12100

12150

12200

12250

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12600

12650

12700

12750

12800

12850

12900

12950

13000

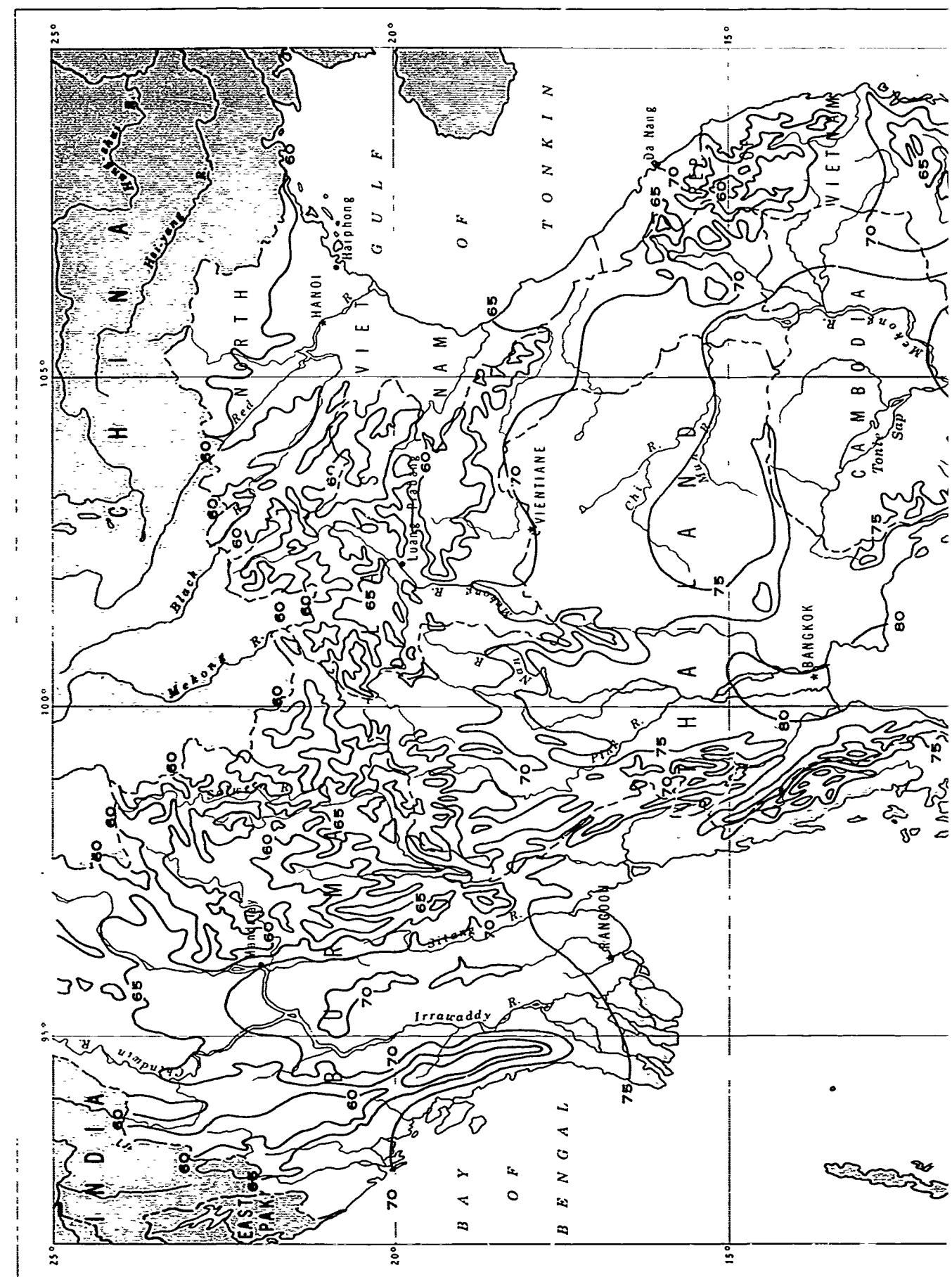
13050

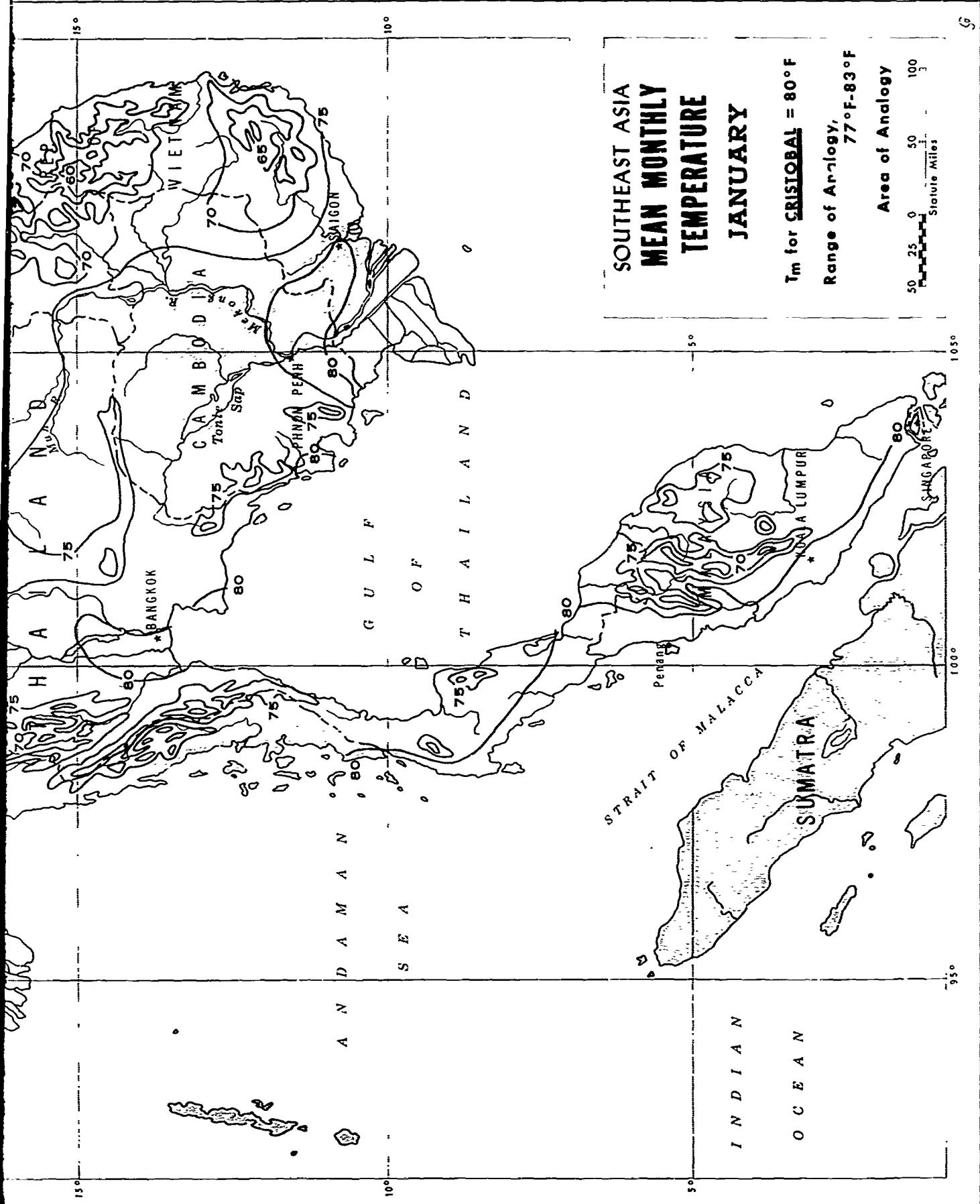
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13150

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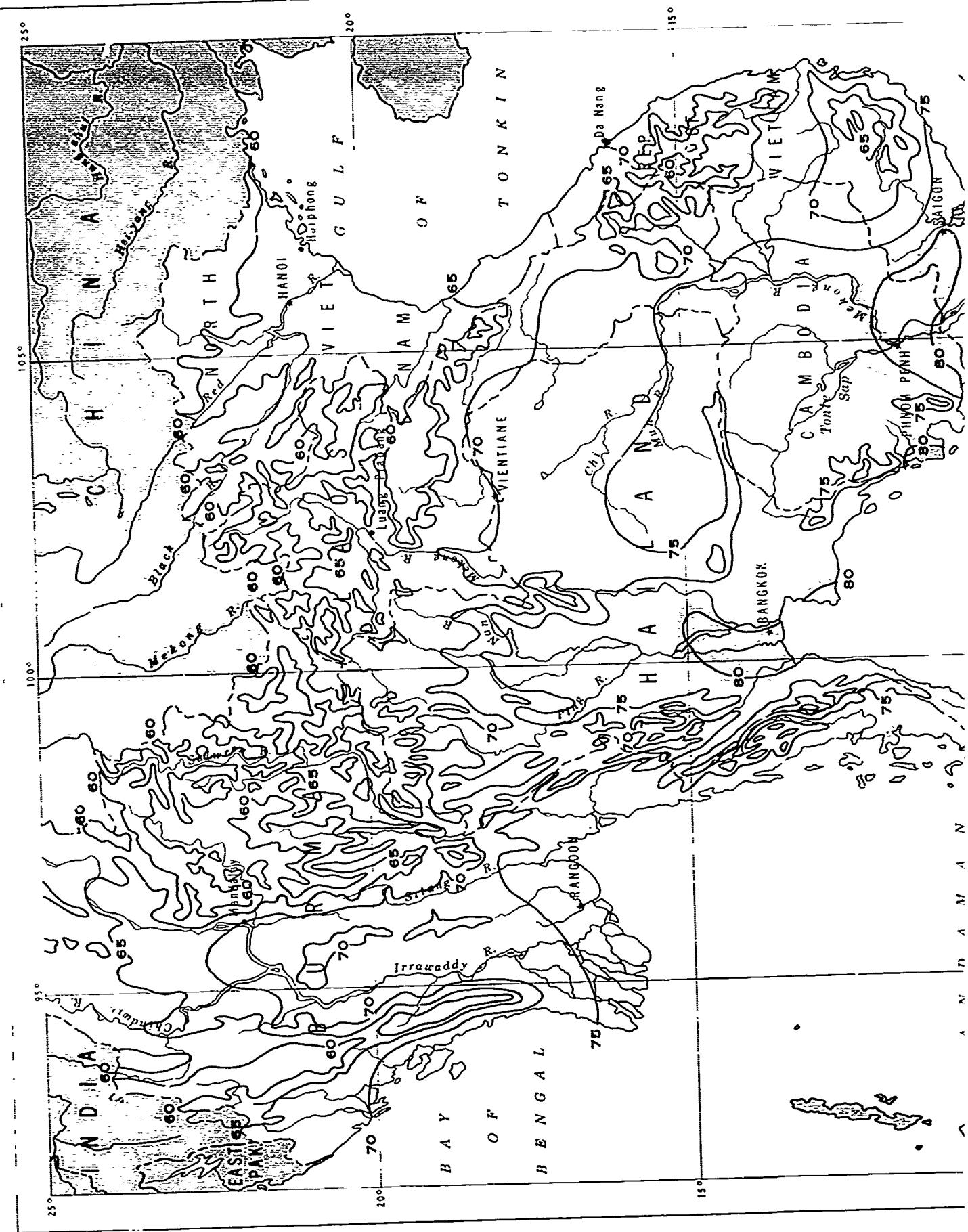
ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA





MAP 3

ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA



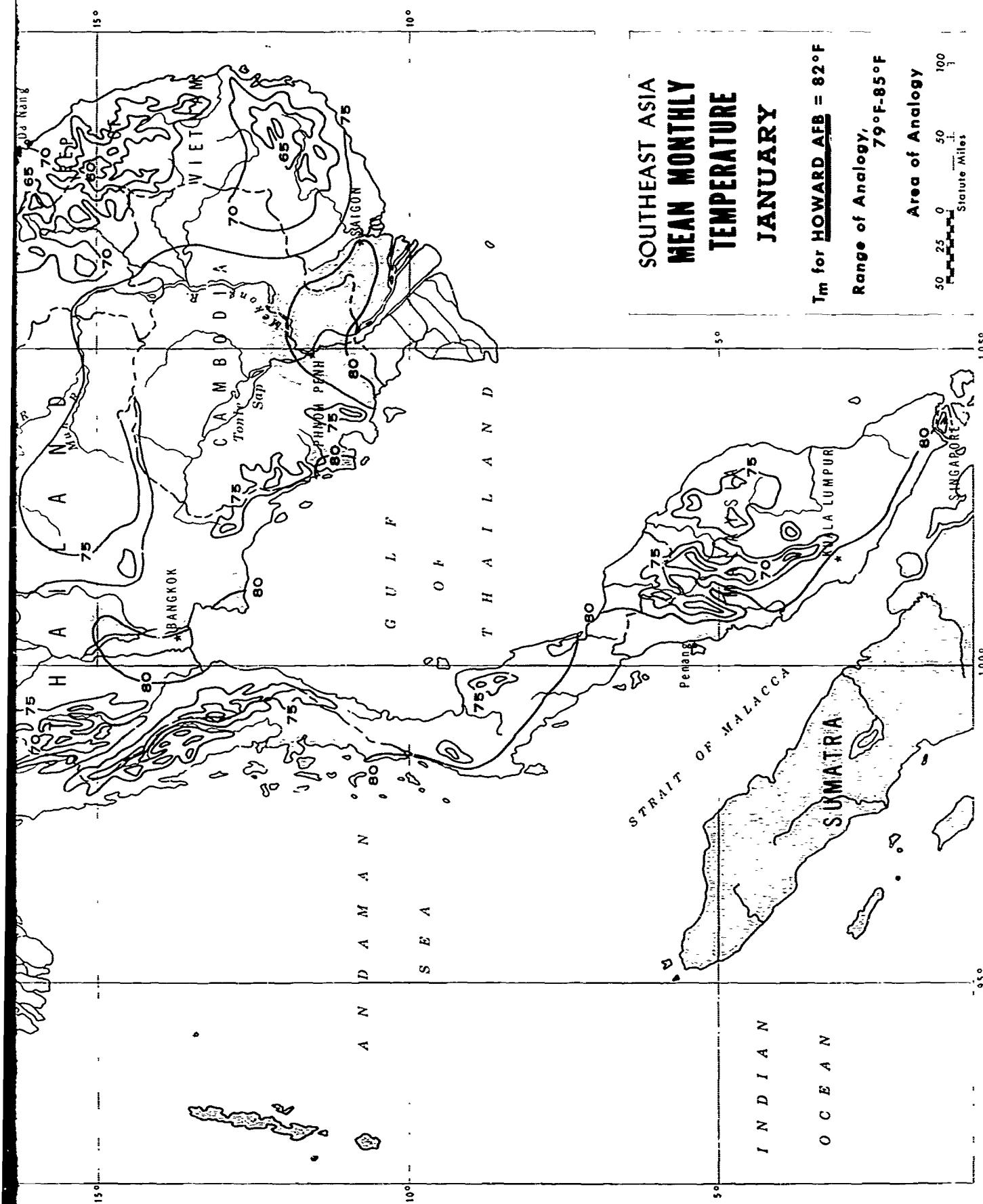
MAP 4

SOUTHEAST ASIA
MEAN MONTHLY
TEMPERATURE
JANUARY

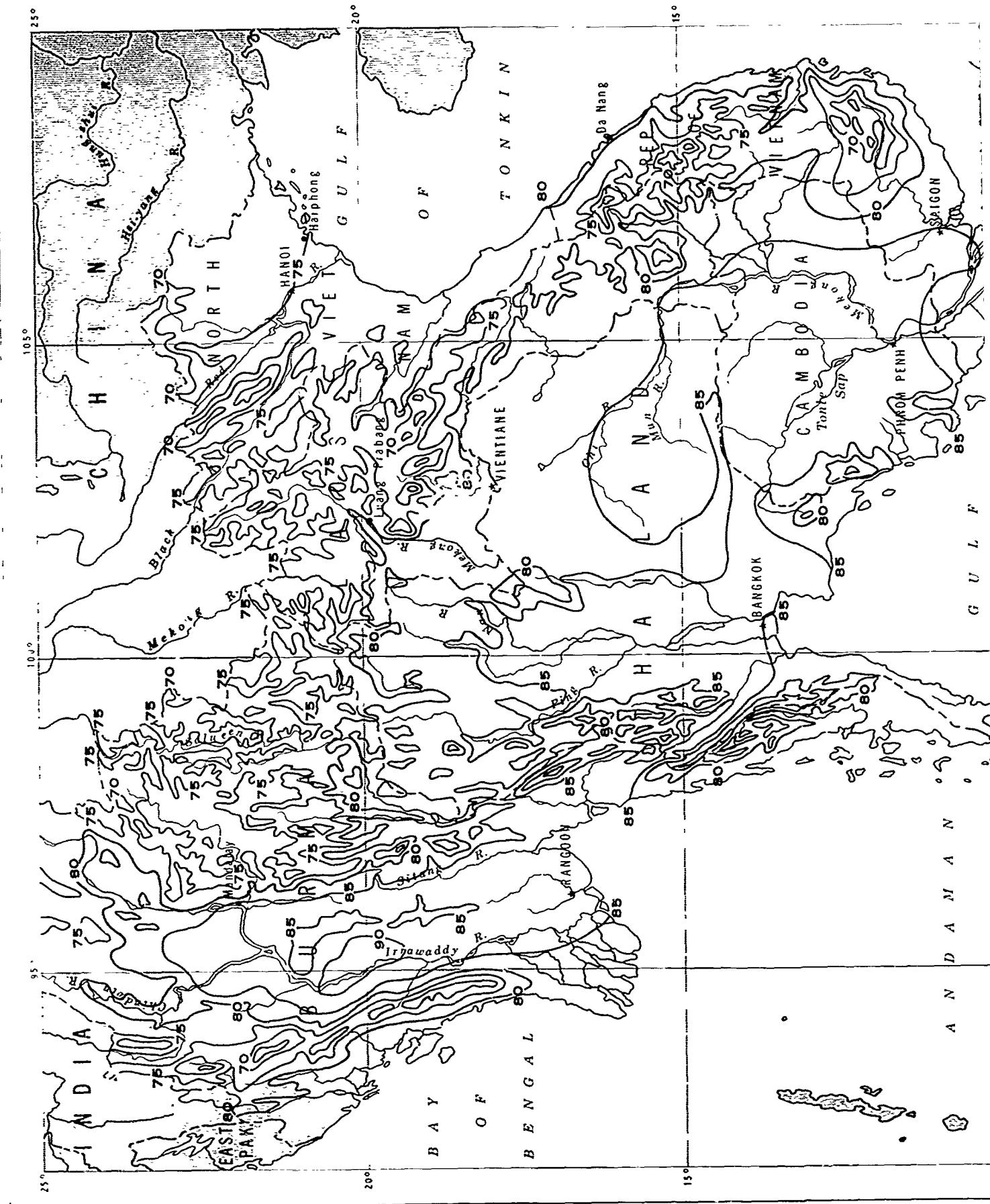
T_m for HOWARD AFB = 82°F

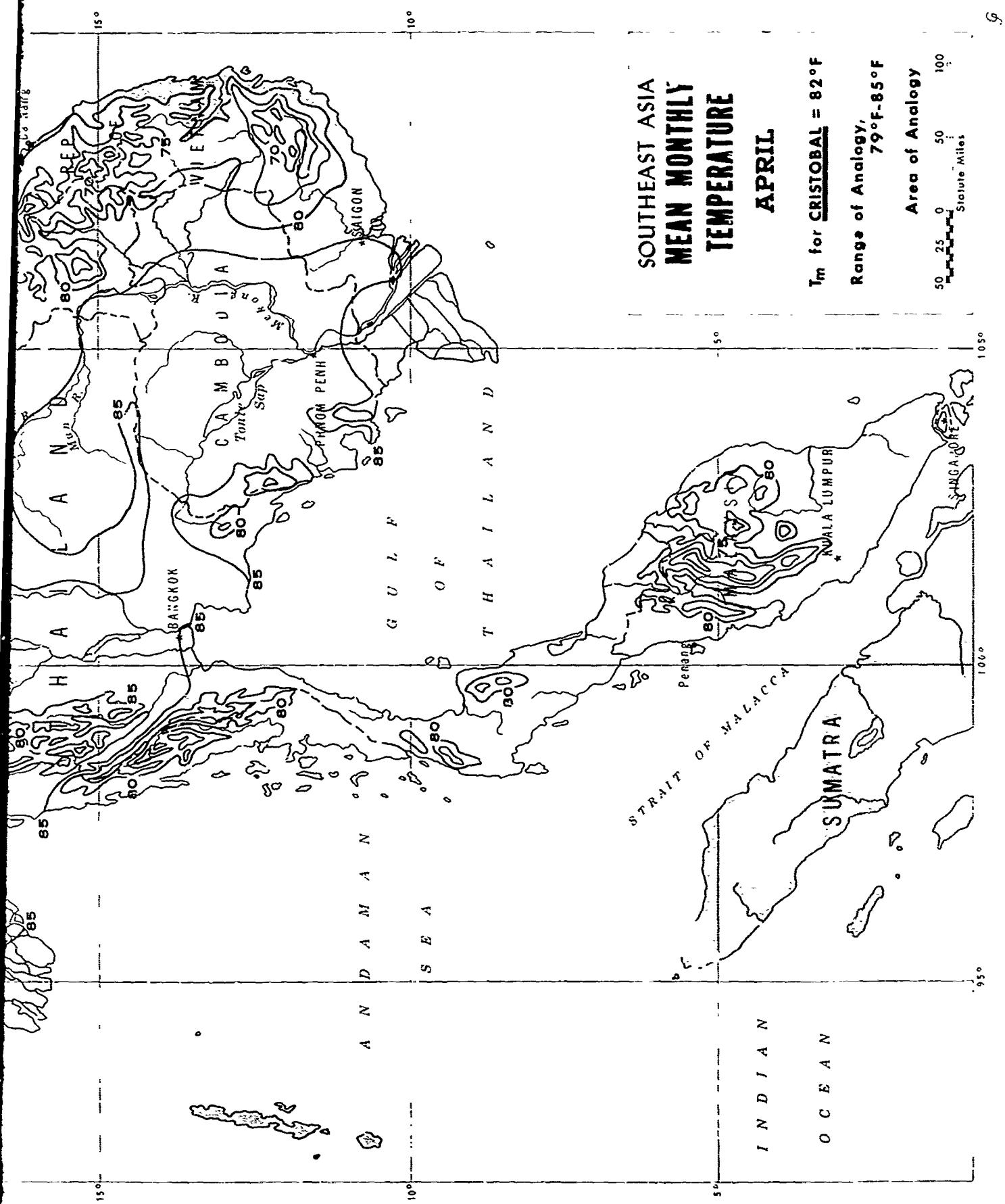
Range of Analogy,
79°F-85°F

Area of Analogy
100
50
0
-50
-100
Statute Miles

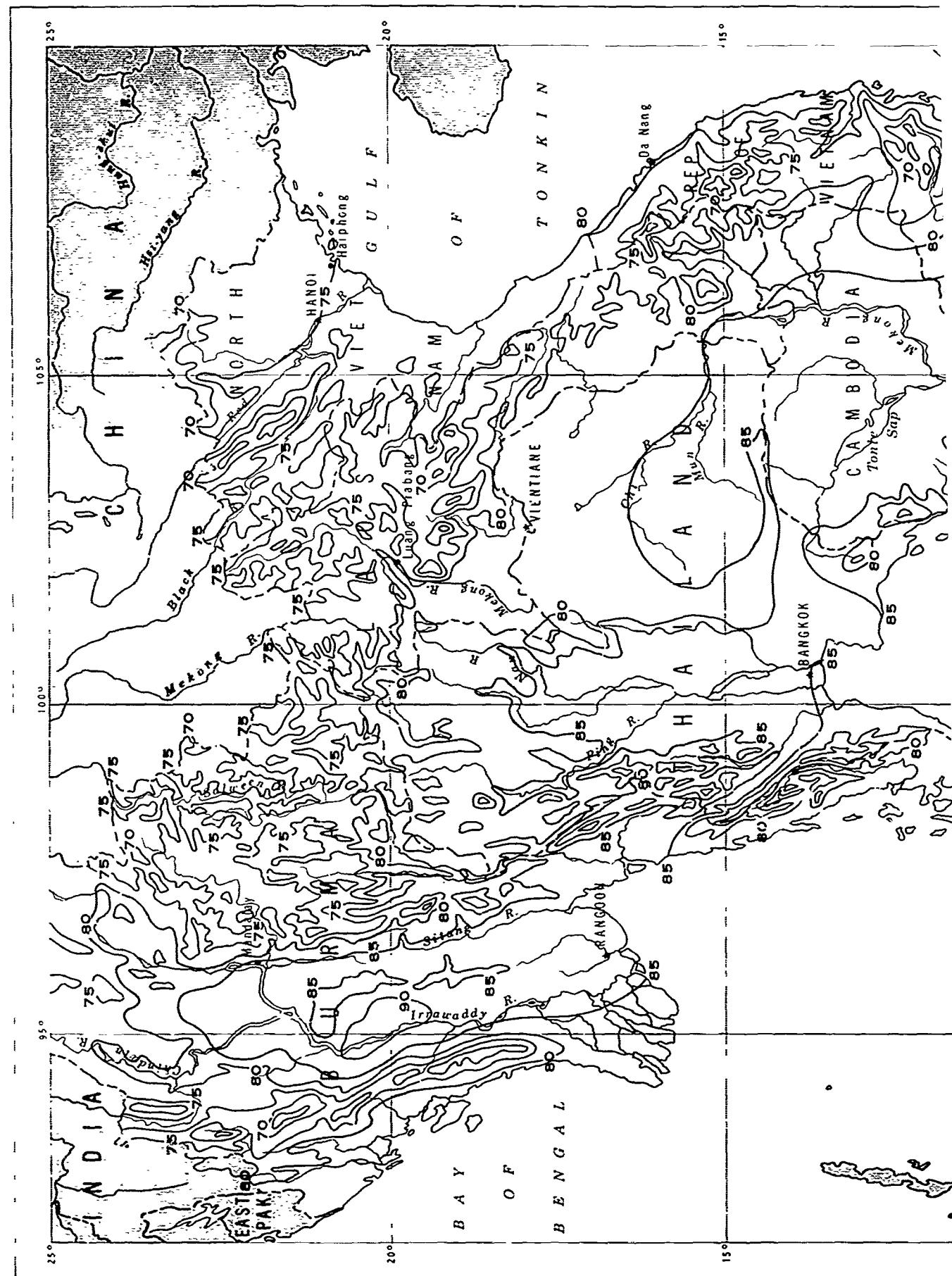


ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA





ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA



MAP 6

SOUTHEAST ASIA
MEAN MONTHLY
TEMPERATURE

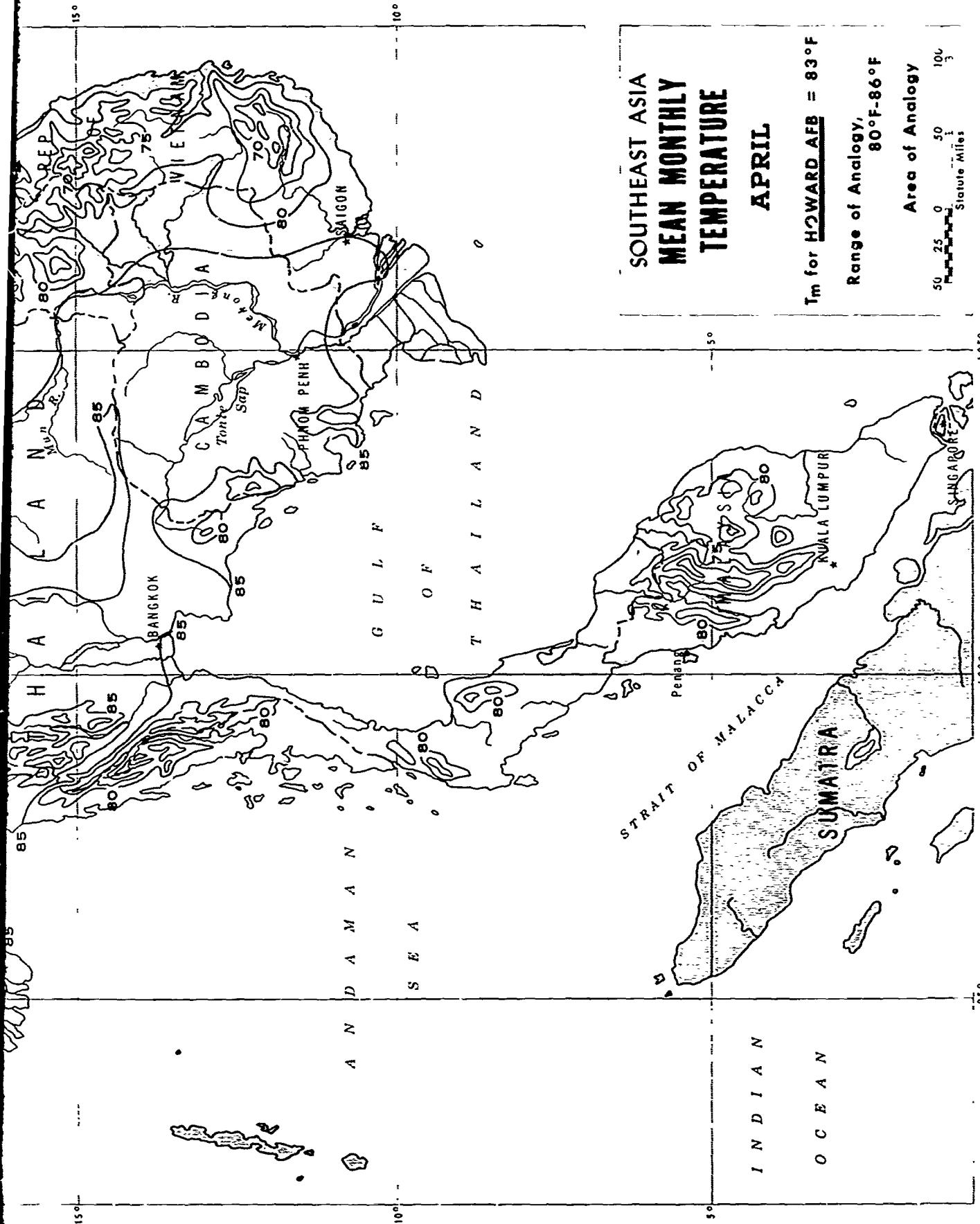
APRIL

T_m for HOWARD AFB = 83°F

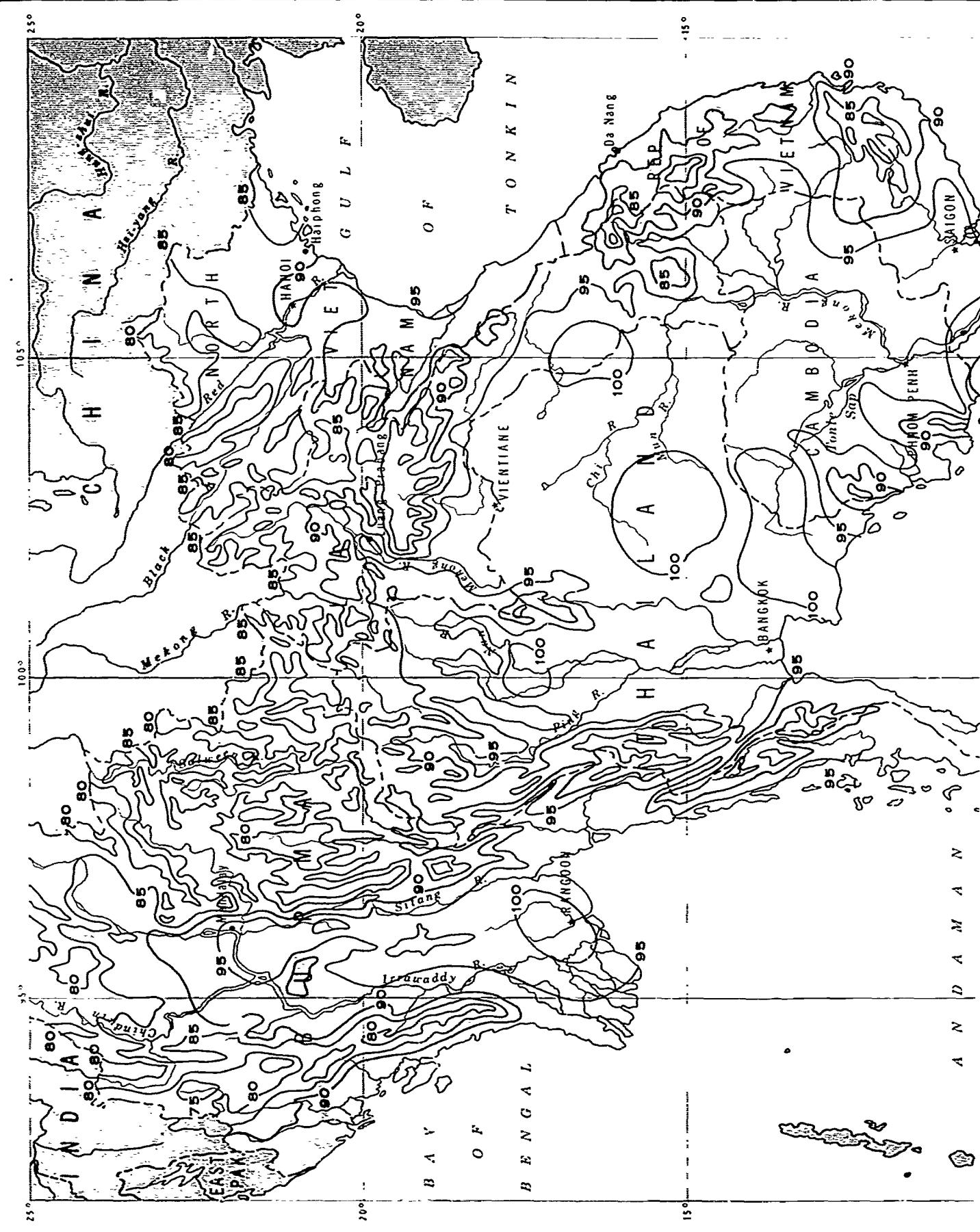
Range of Analogy,
80°F-86°F

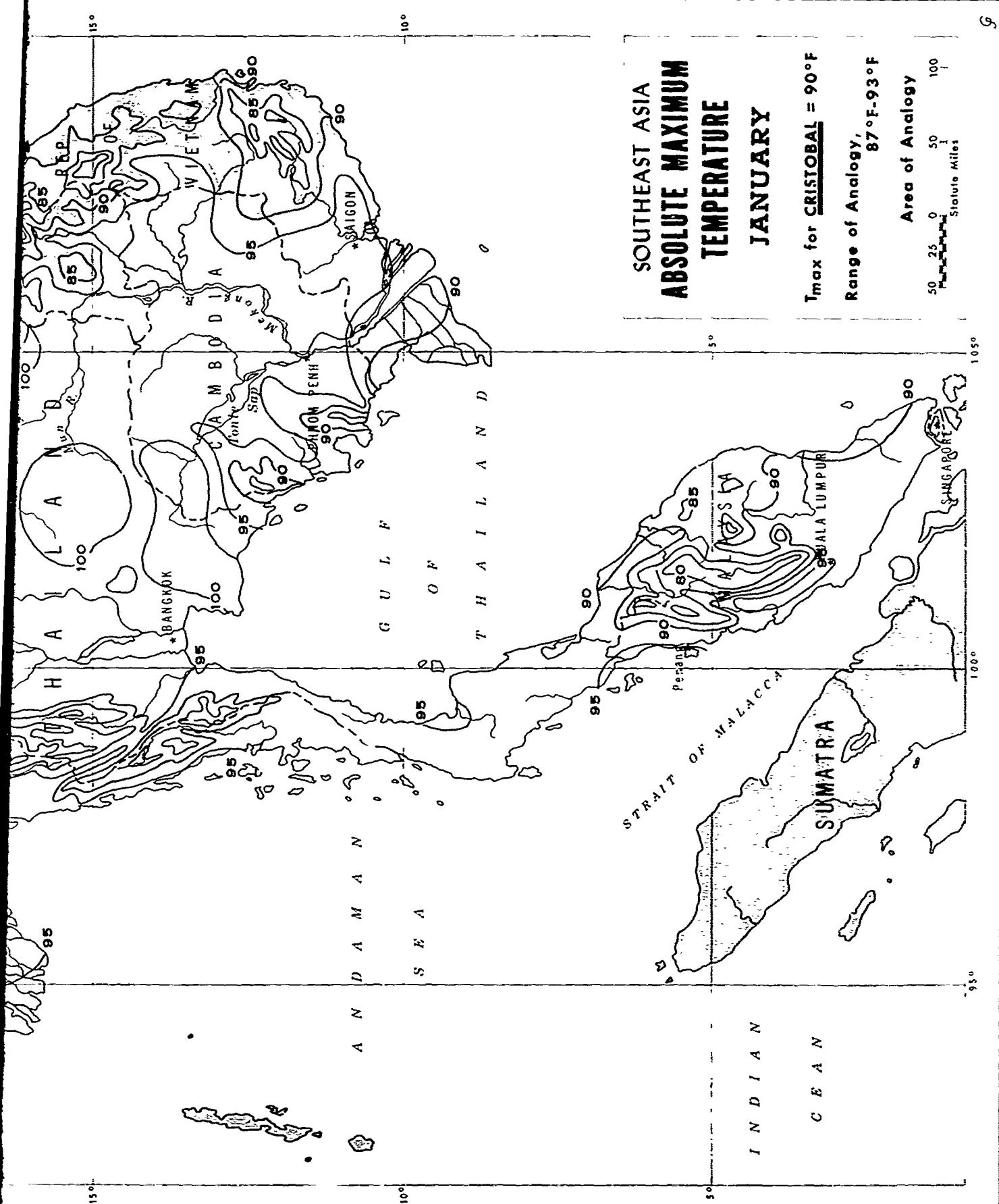
Area of Analogy
Statute Miles

6



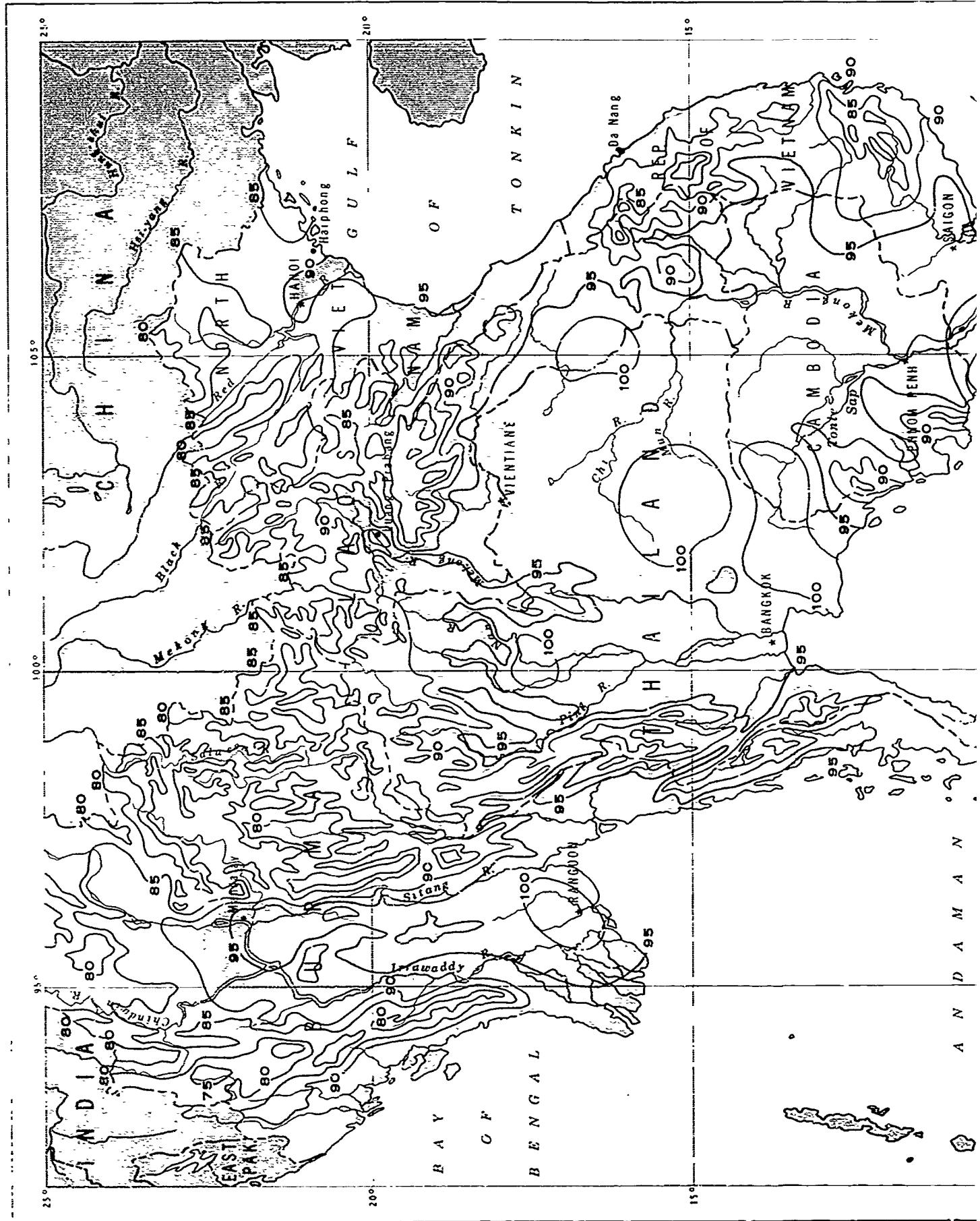
ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA





MAP 7

ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA



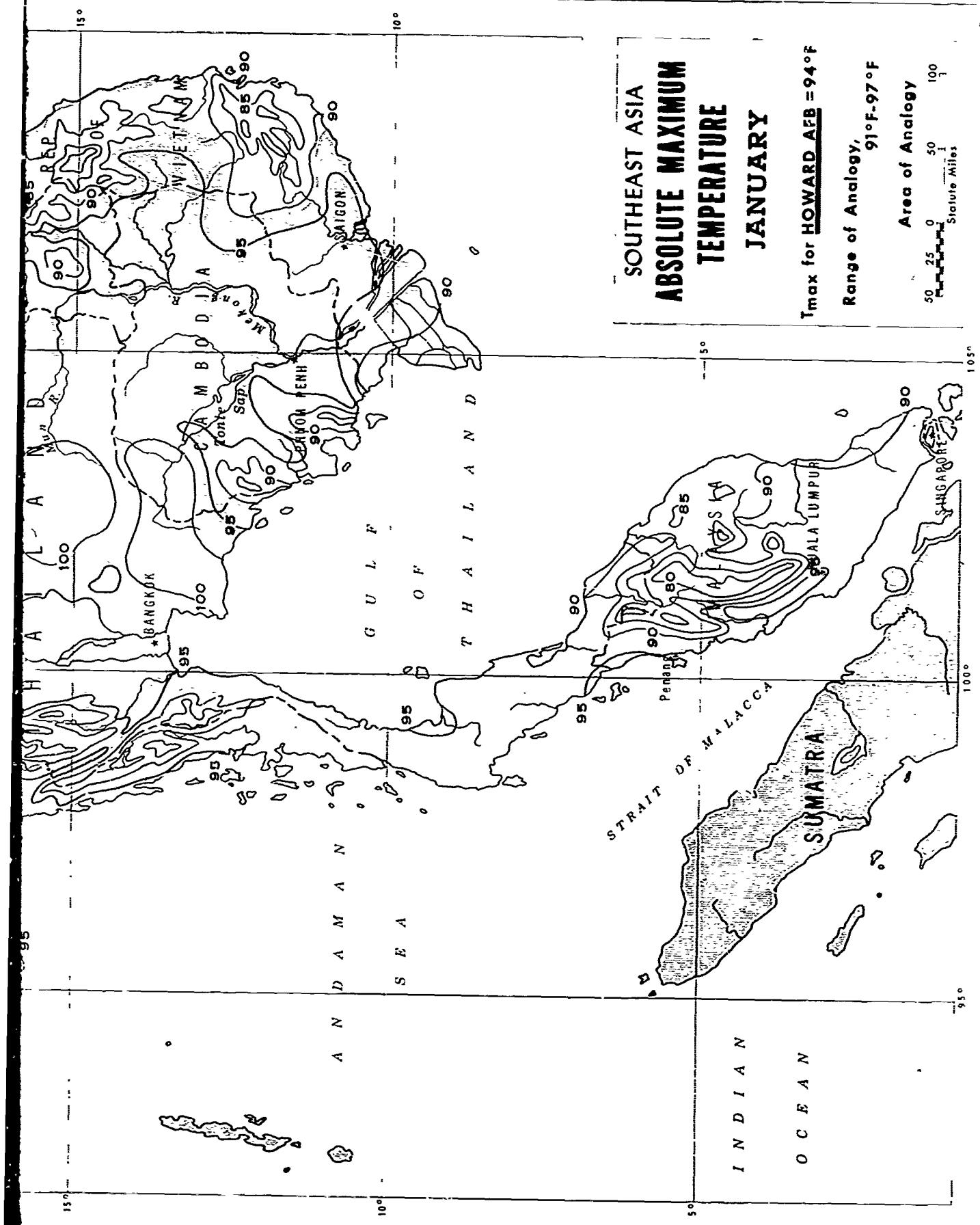
MAP 8

SOUTHEAST ASIA
ABSOLUTE MAXIMUM
TEMPERATURE
JANUARY

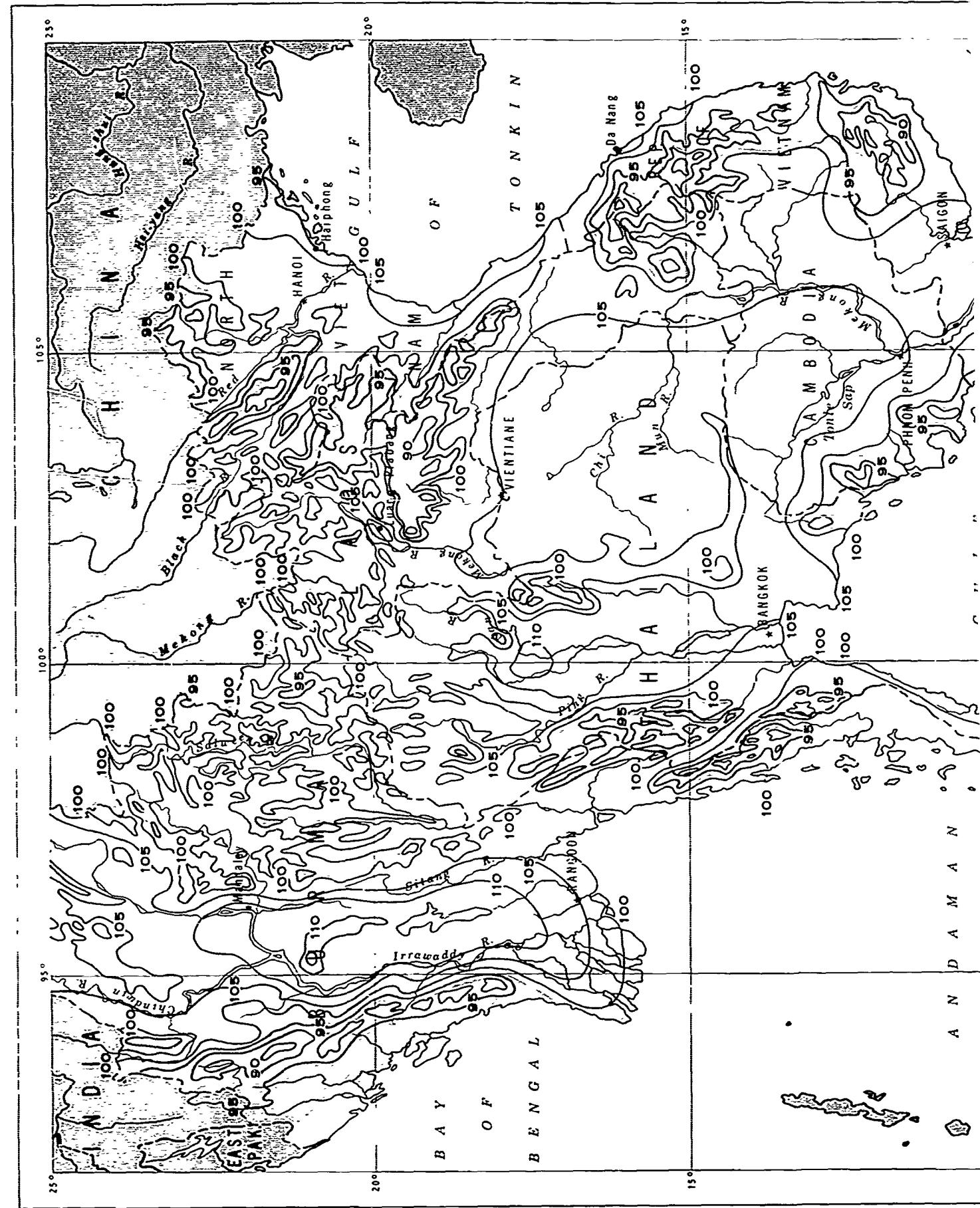
T_{max} for HOWARD AFB = 94°F

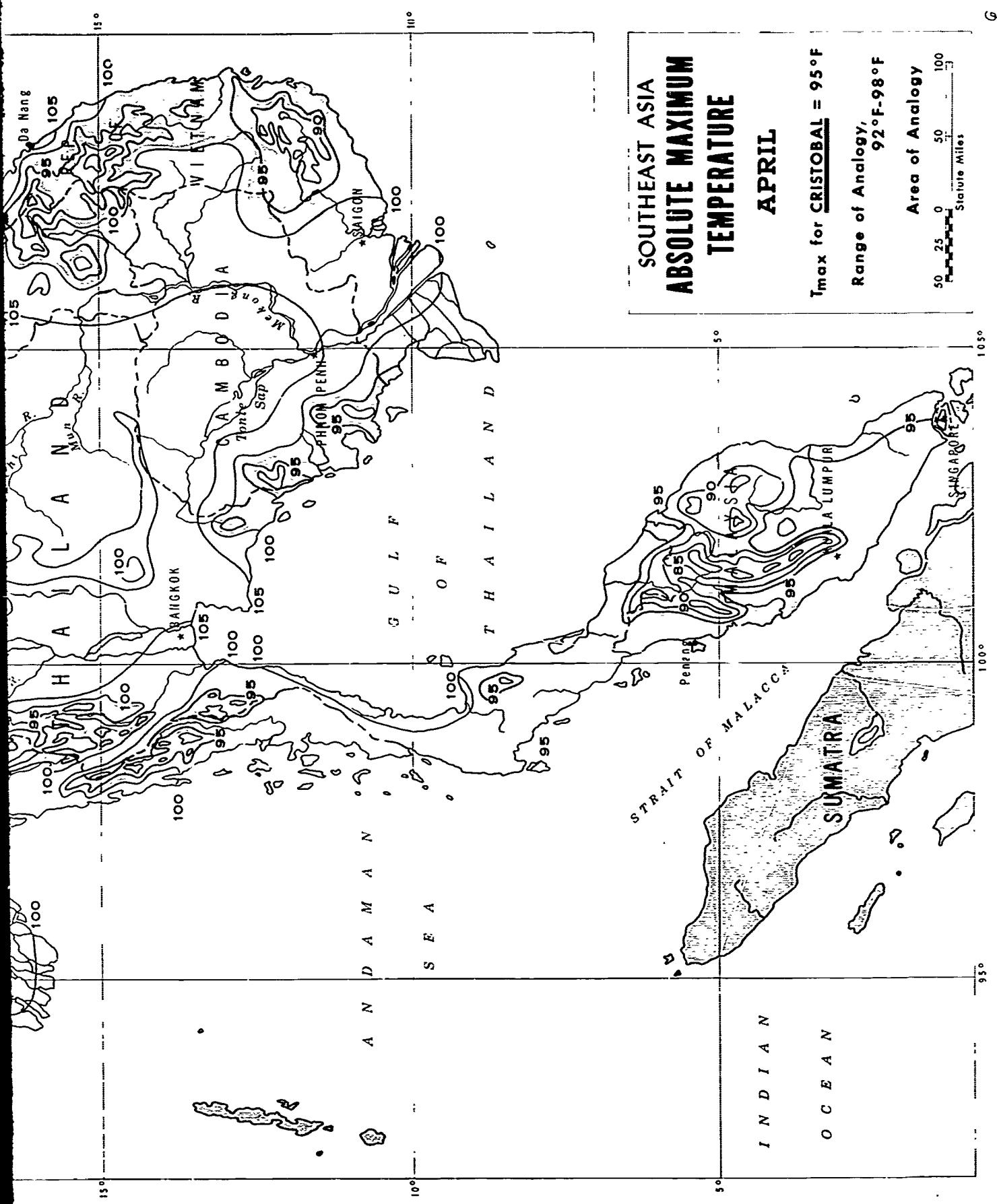
Range of Analogy, 91°F-97°F

Area of Analogy
50 25 0 50 100
Statute Miles

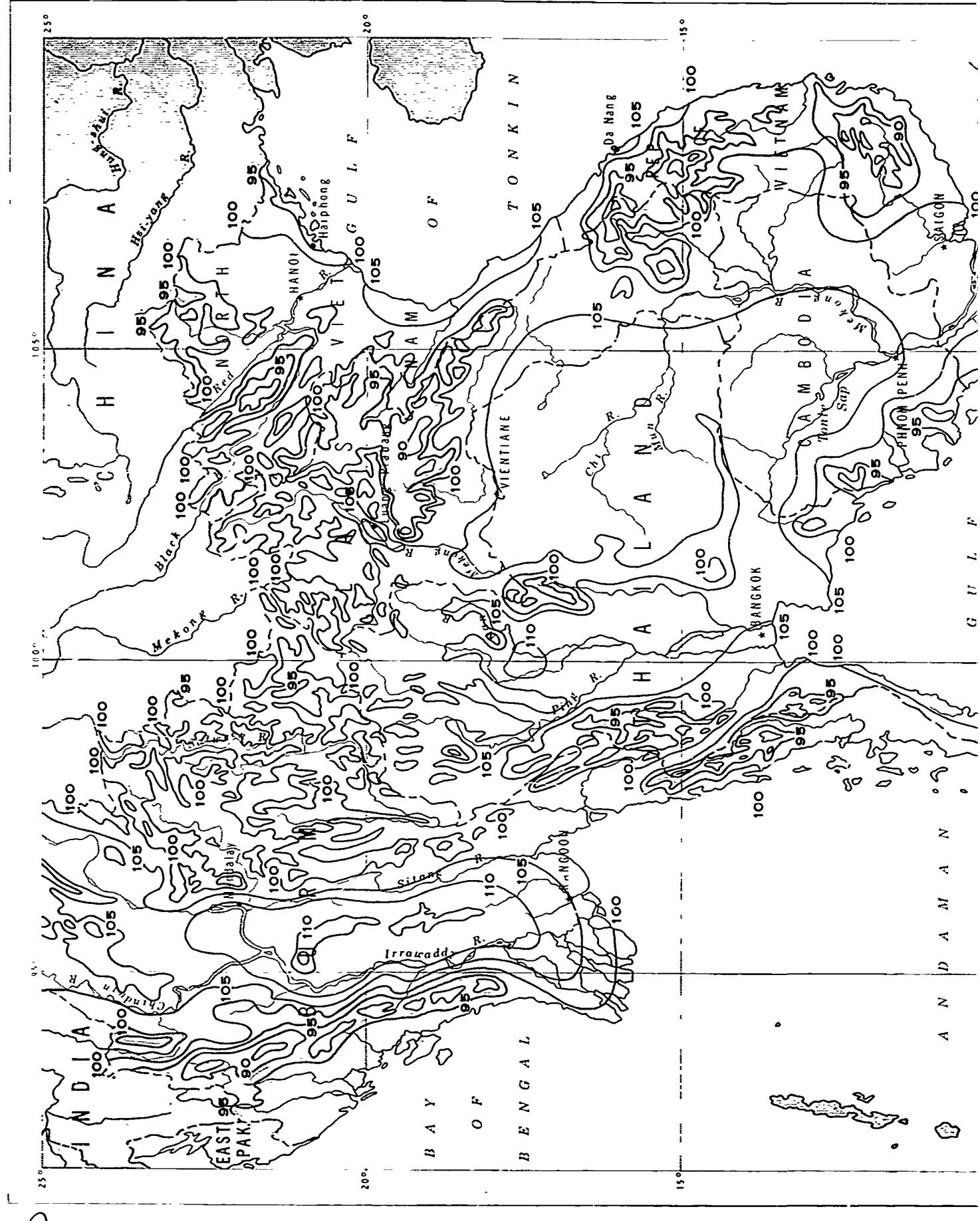


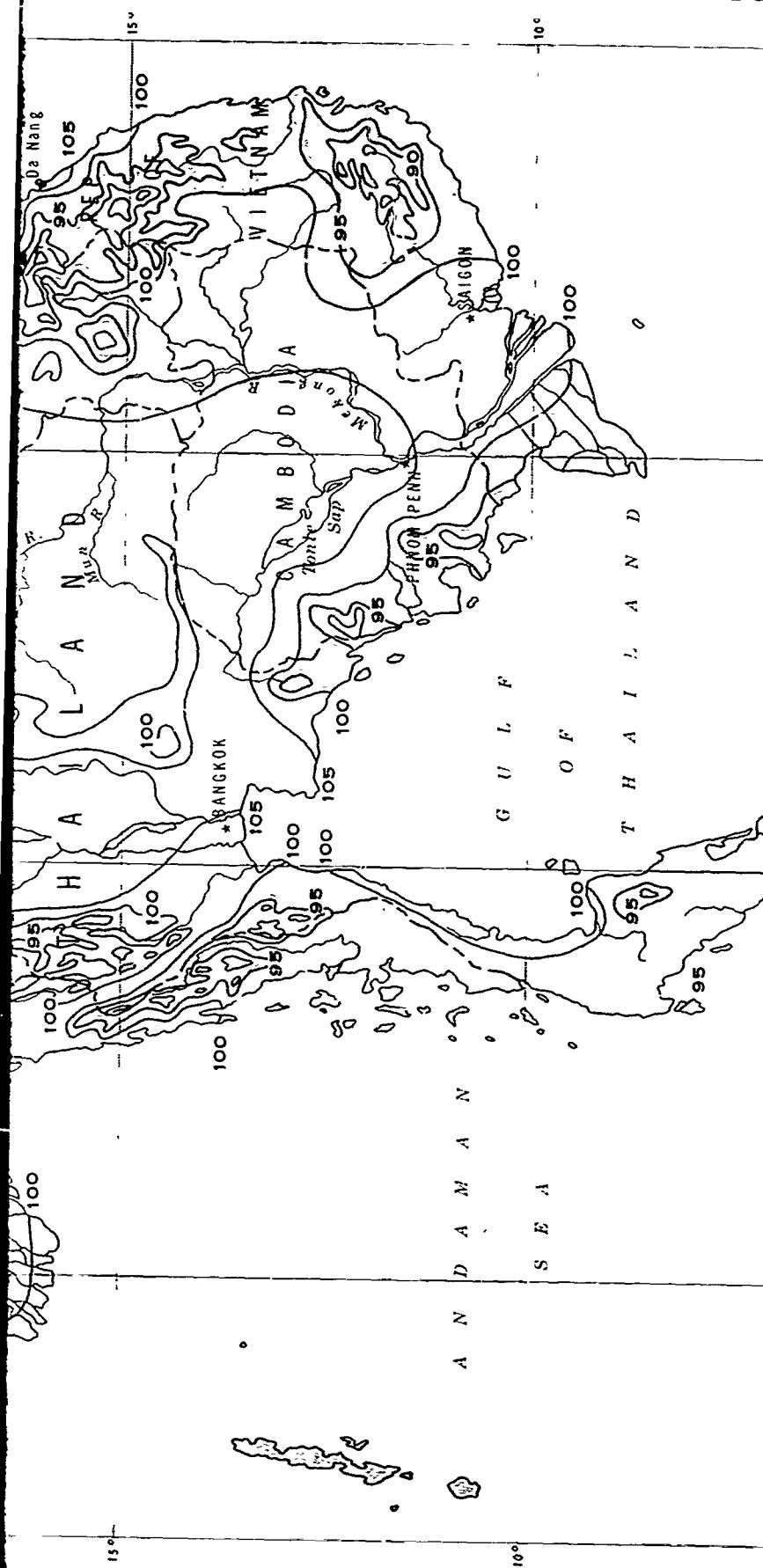
ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA





ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA





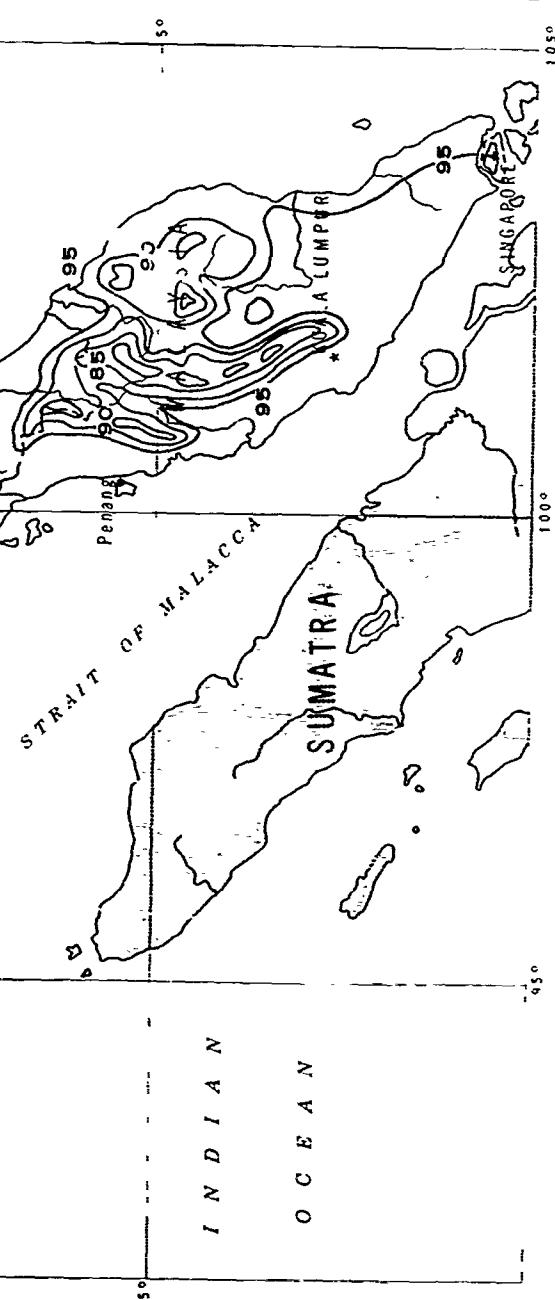
SOUTHEAST ASIA ABSOLUTE MAXIMUM TEMPERATURE

APRIL

T_{max} for HOWARD AFB = 97°F

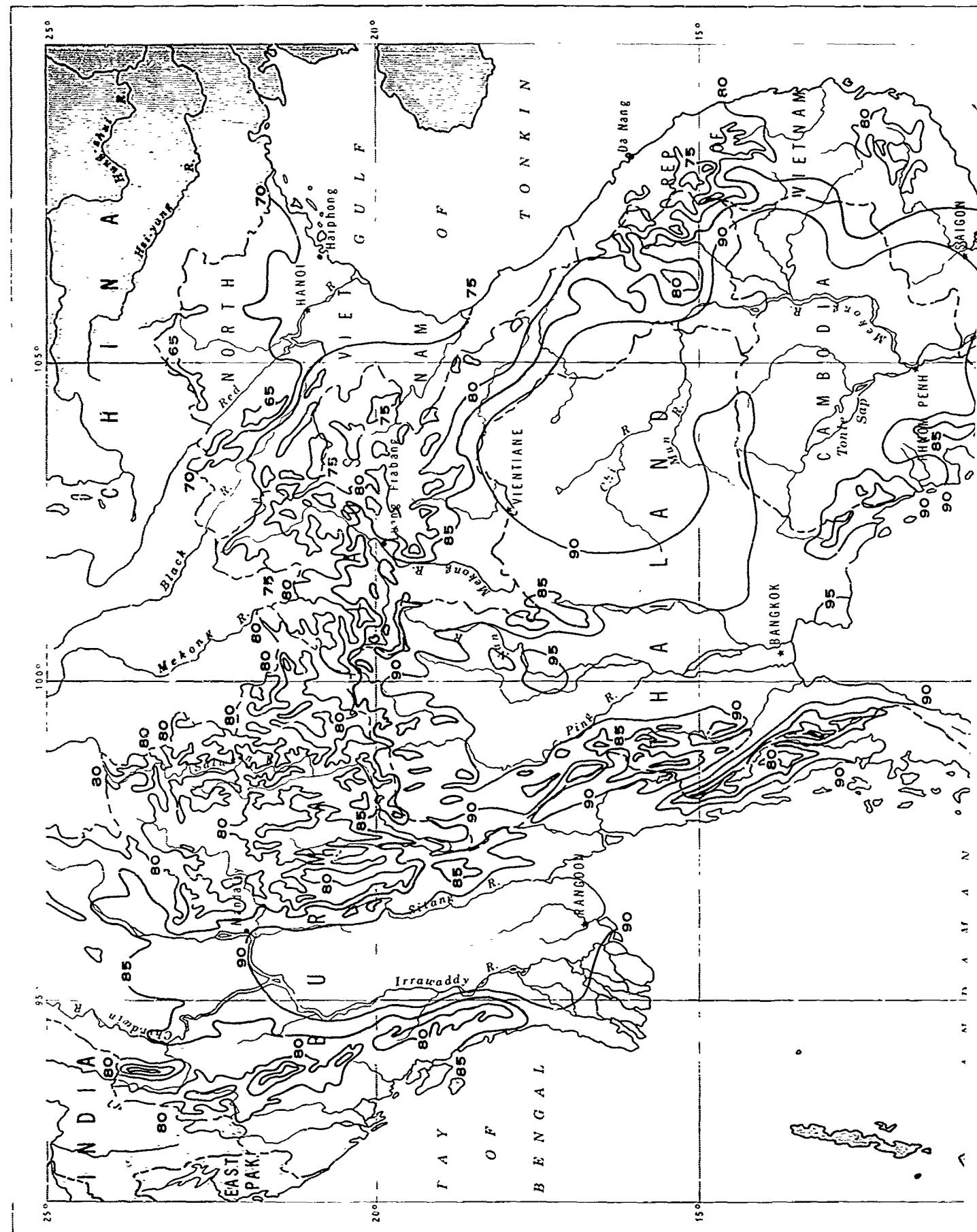
Range of Analogy, 94°F-100°F

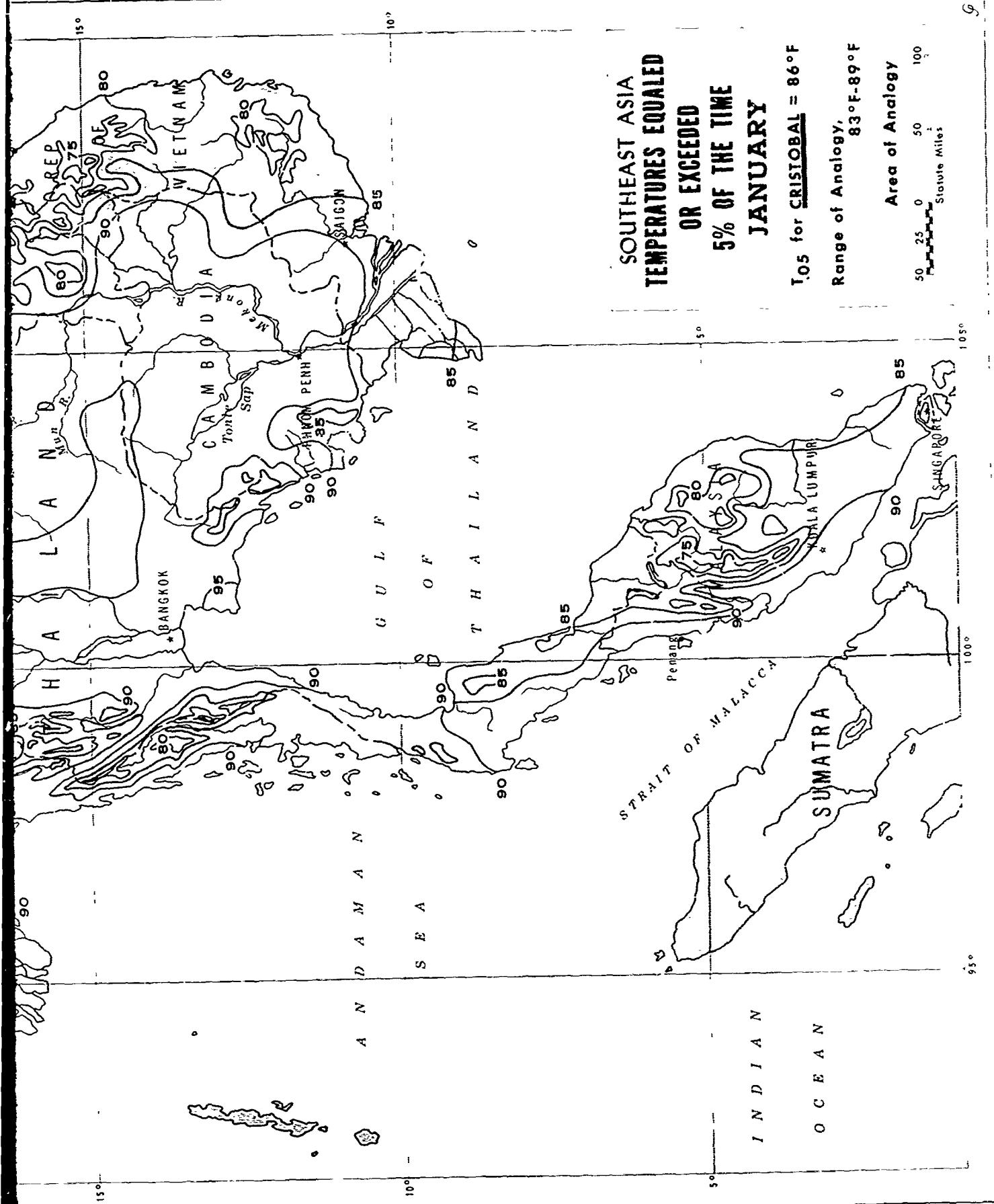
Area of Analogy
Statute Miles



MAP 10

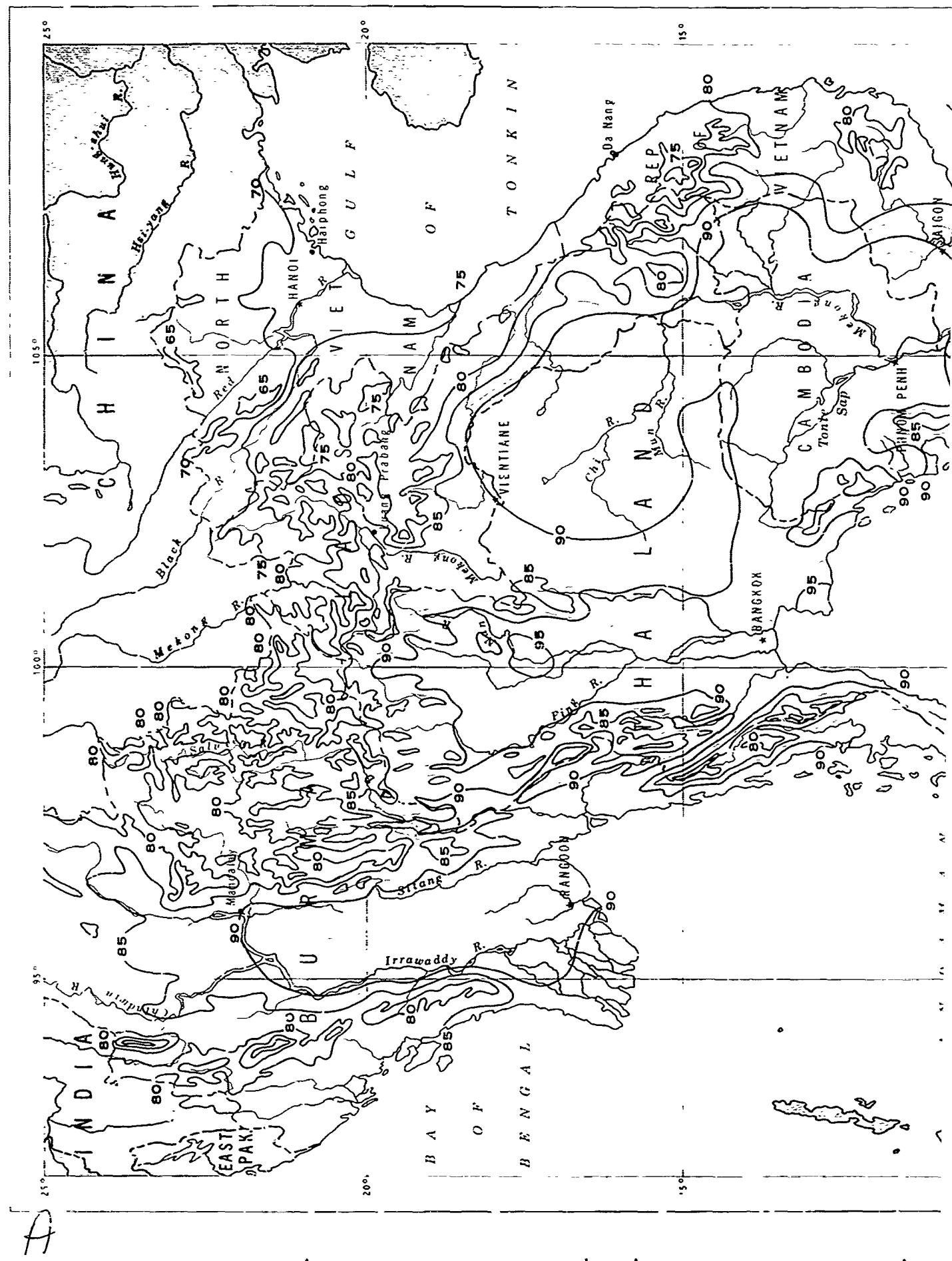
ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA



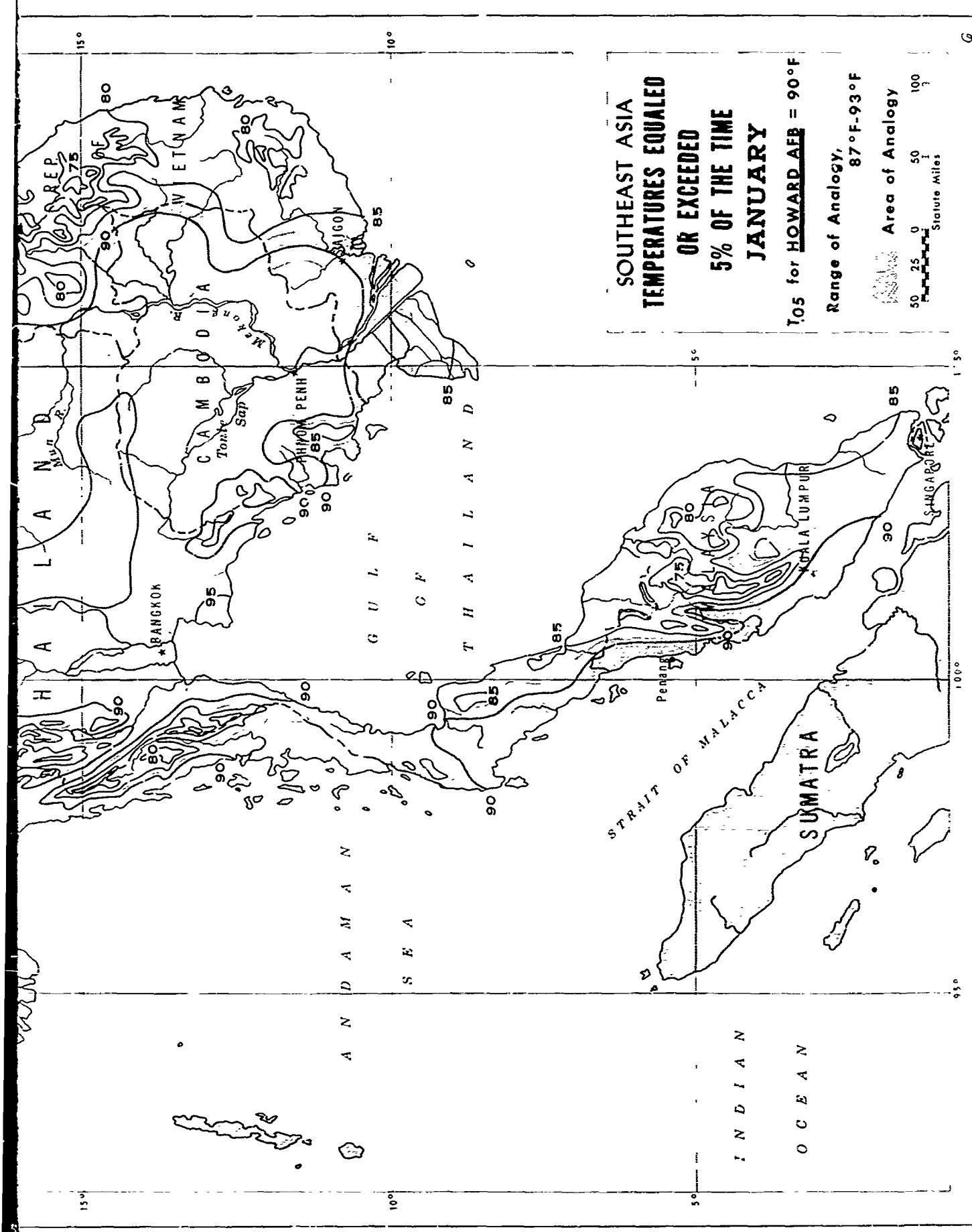


B

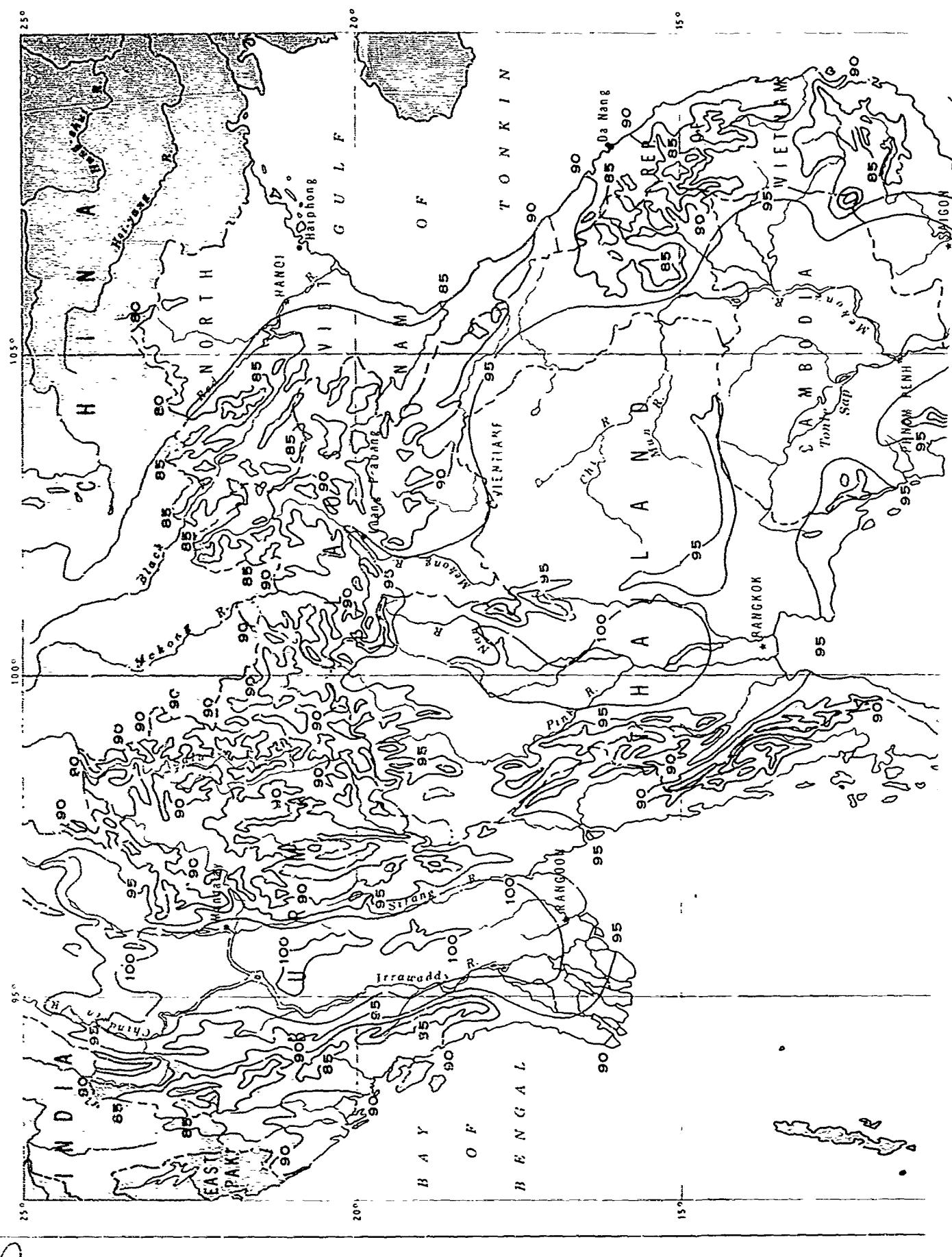
ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA

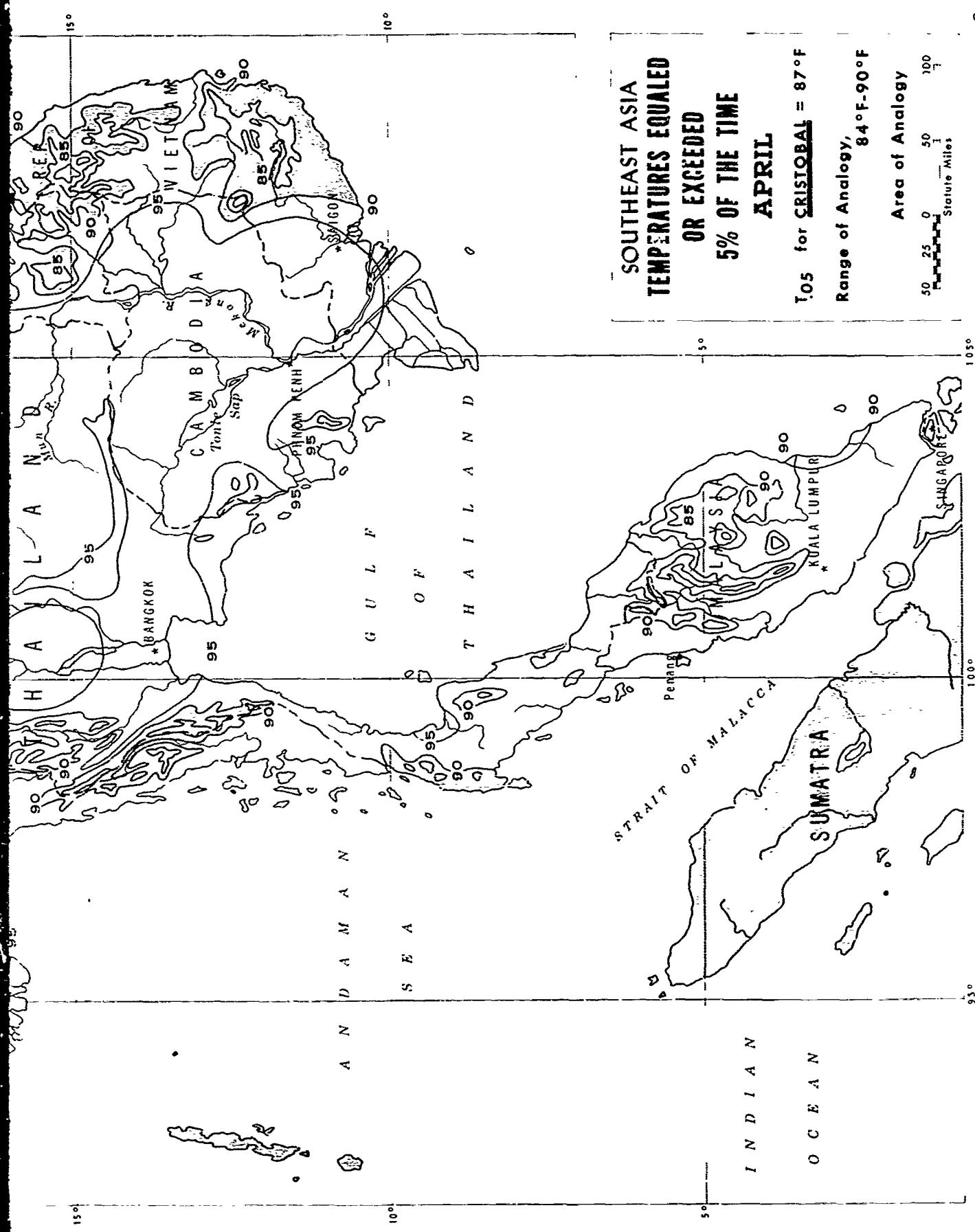


MAP 12



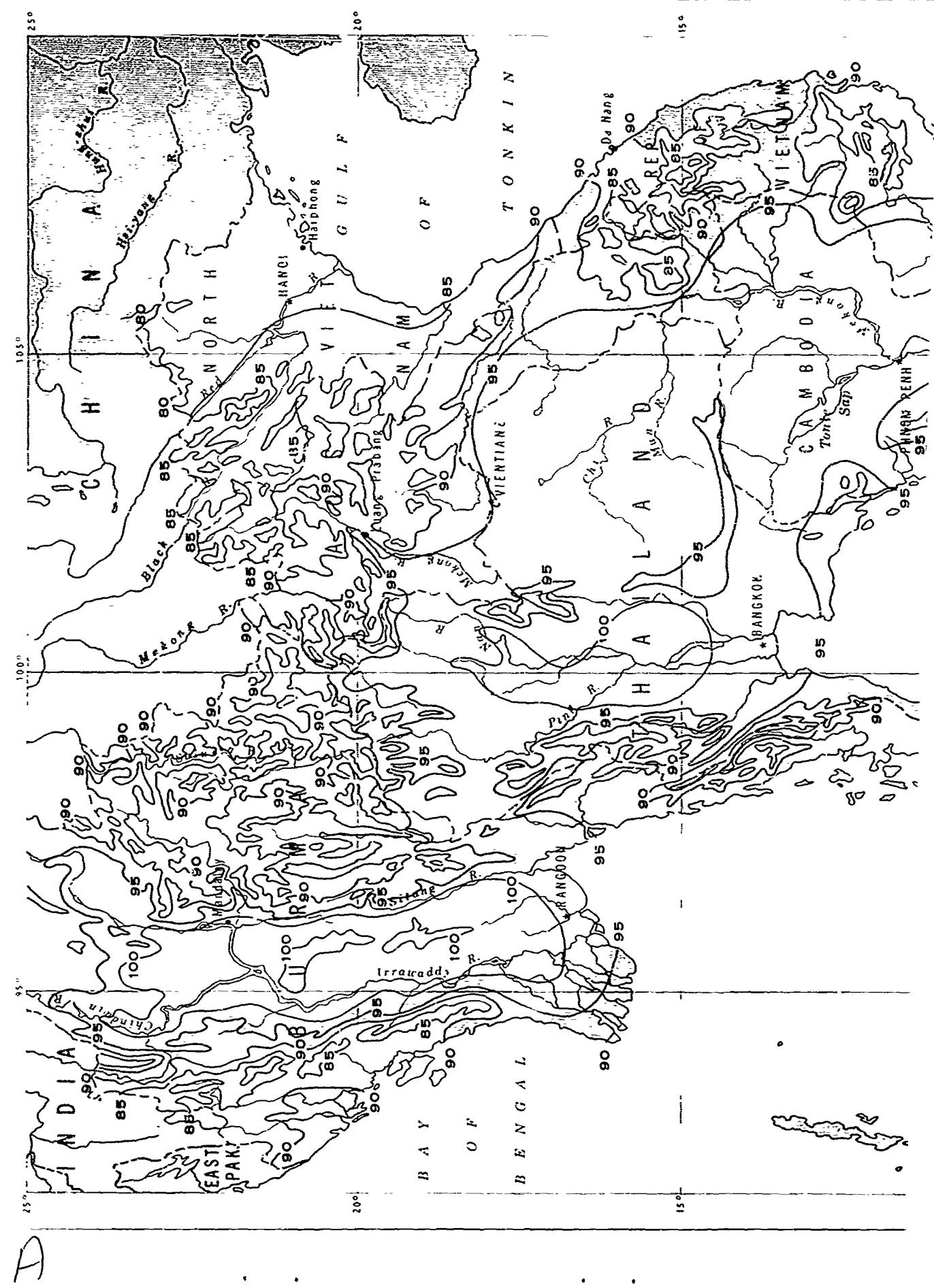
ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA

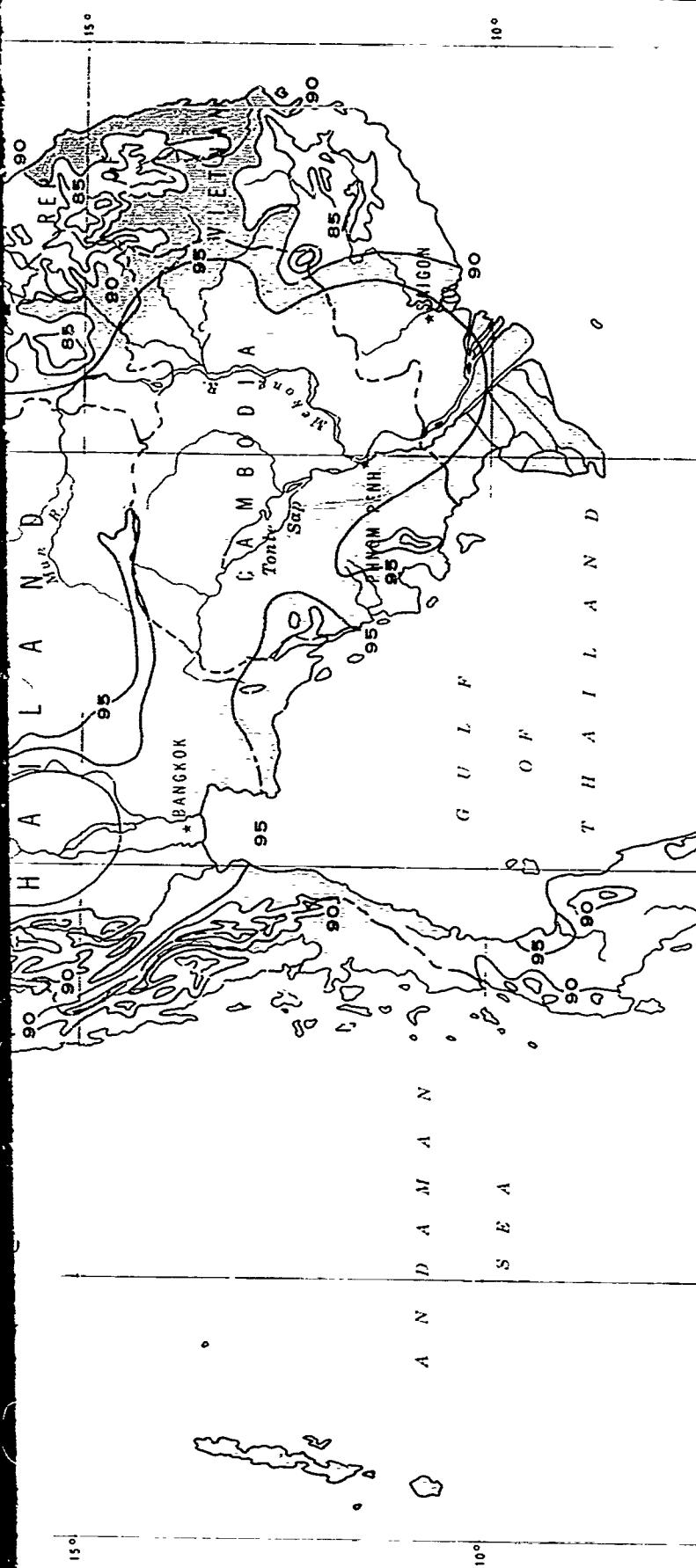




MAP 13

ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA





SOUTHEAST ASIA
TEMPERATURES EQUALLED
OR EXCEEDED

5% OF THE TIME

APRIL

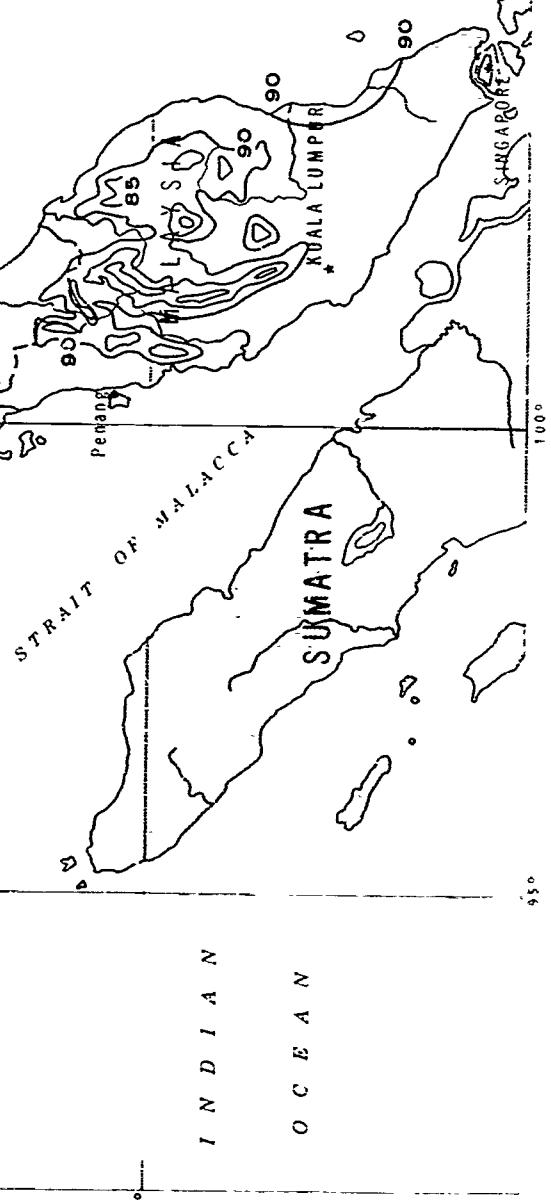
T.05 for HCWARD AFB = 93° F

Range of Analogy,

90° F - 96° F

Area of Analogy

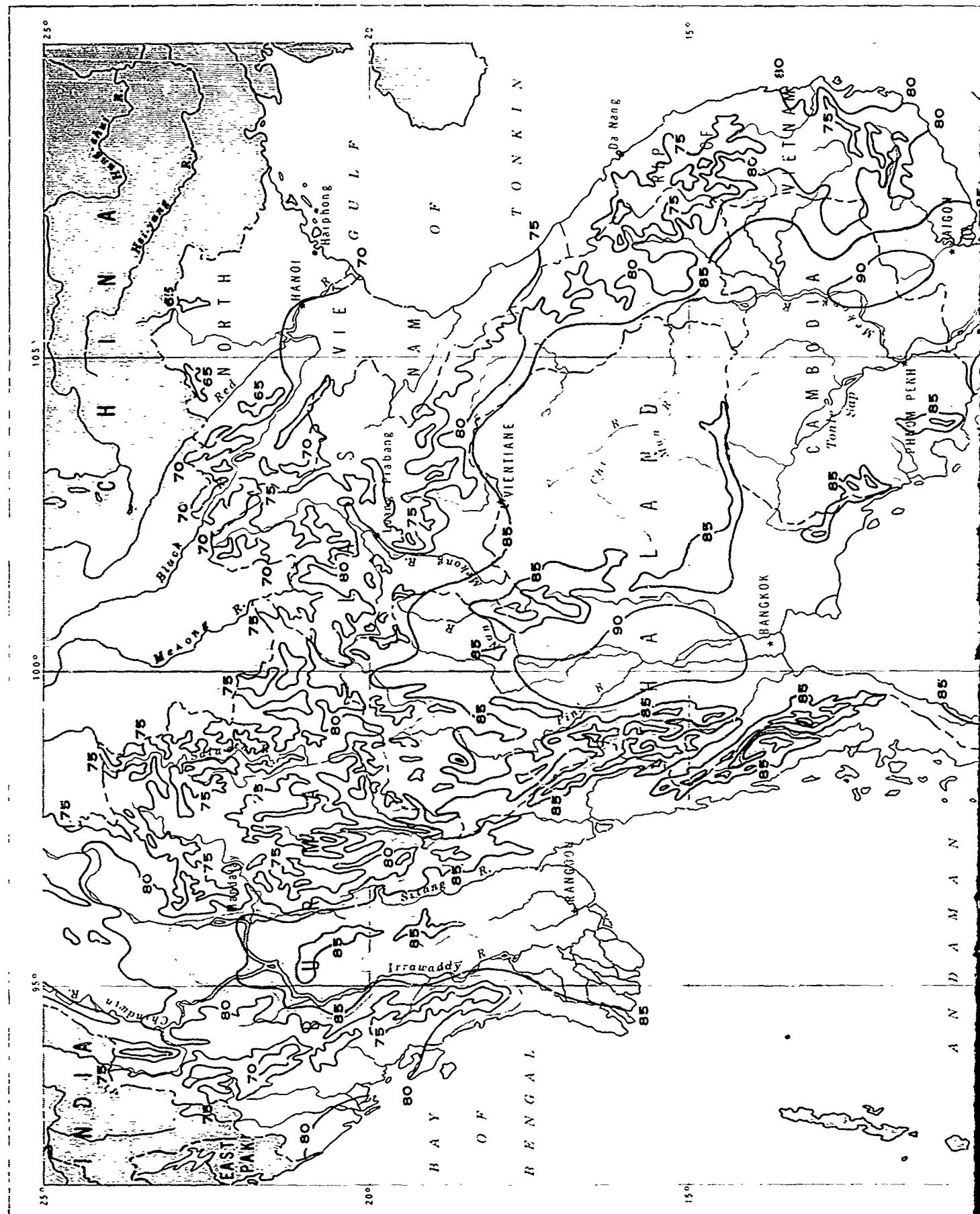
50 25 0 50 100
Statute Miles

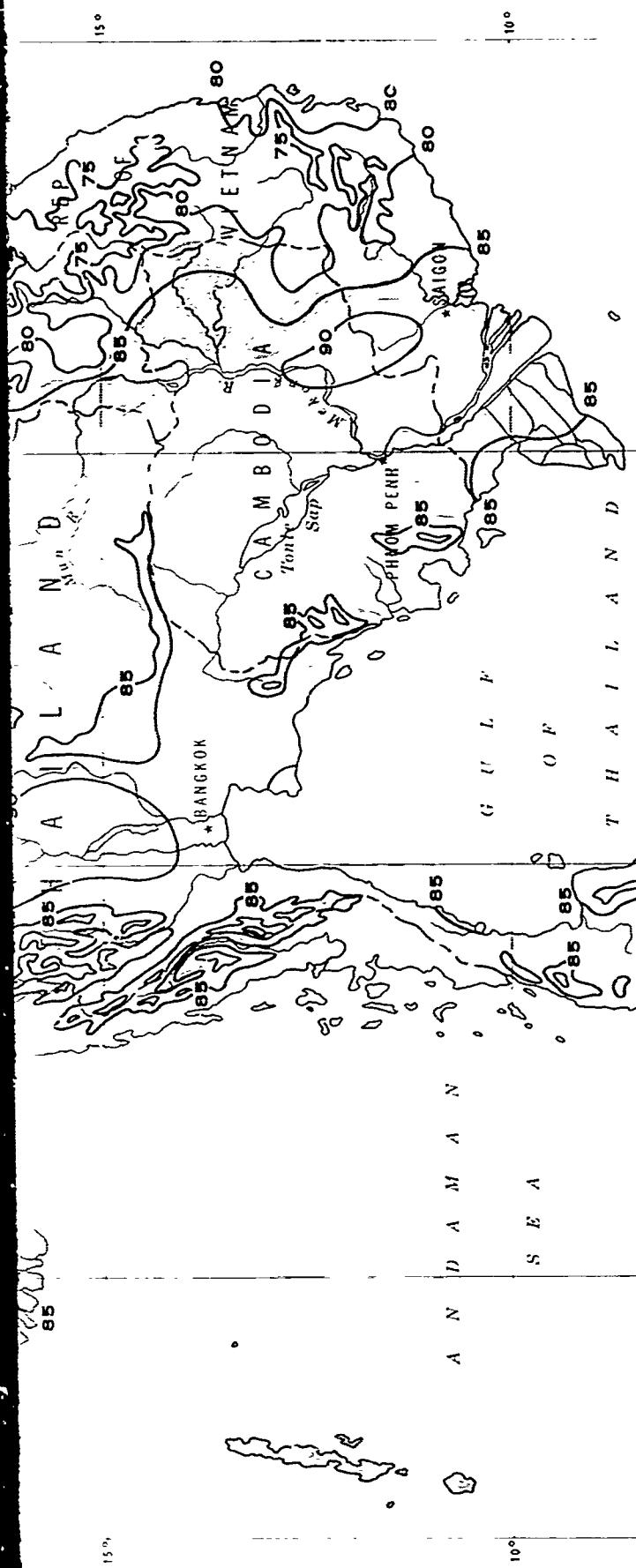


MAP 14

B

ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA





SOUTHEAST ASIA
TEMPERATURES EQUALLED
OR EXCEEDED

10% OF THE TIME

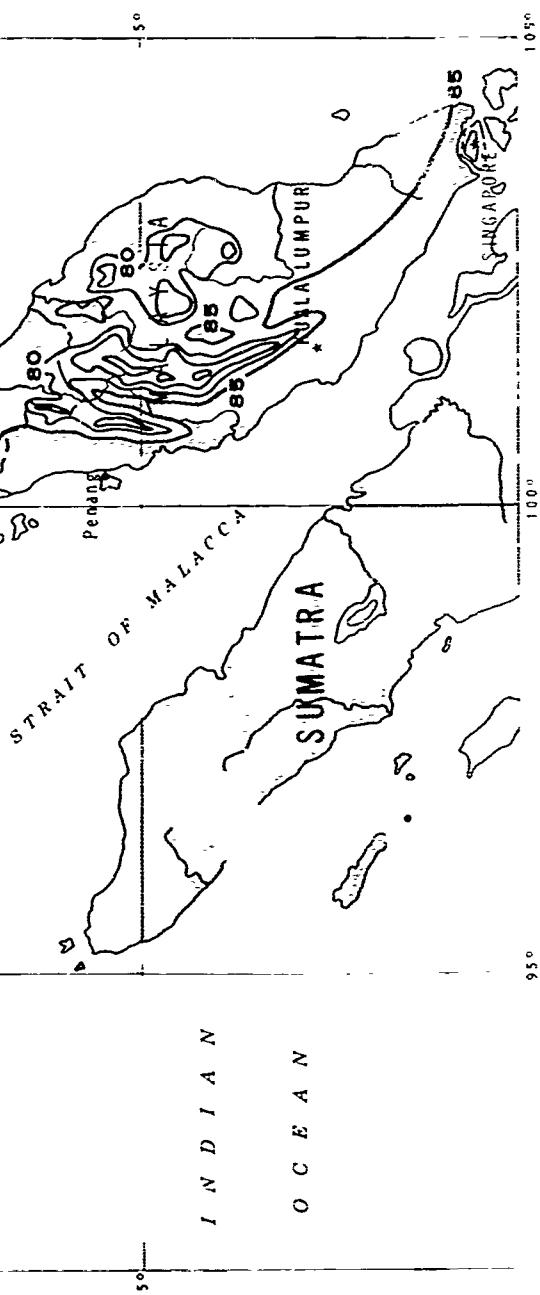
JANUARY

T₁₀ for CRISTOBAL = 85°F

Range of Analogy,
82°F-88°F

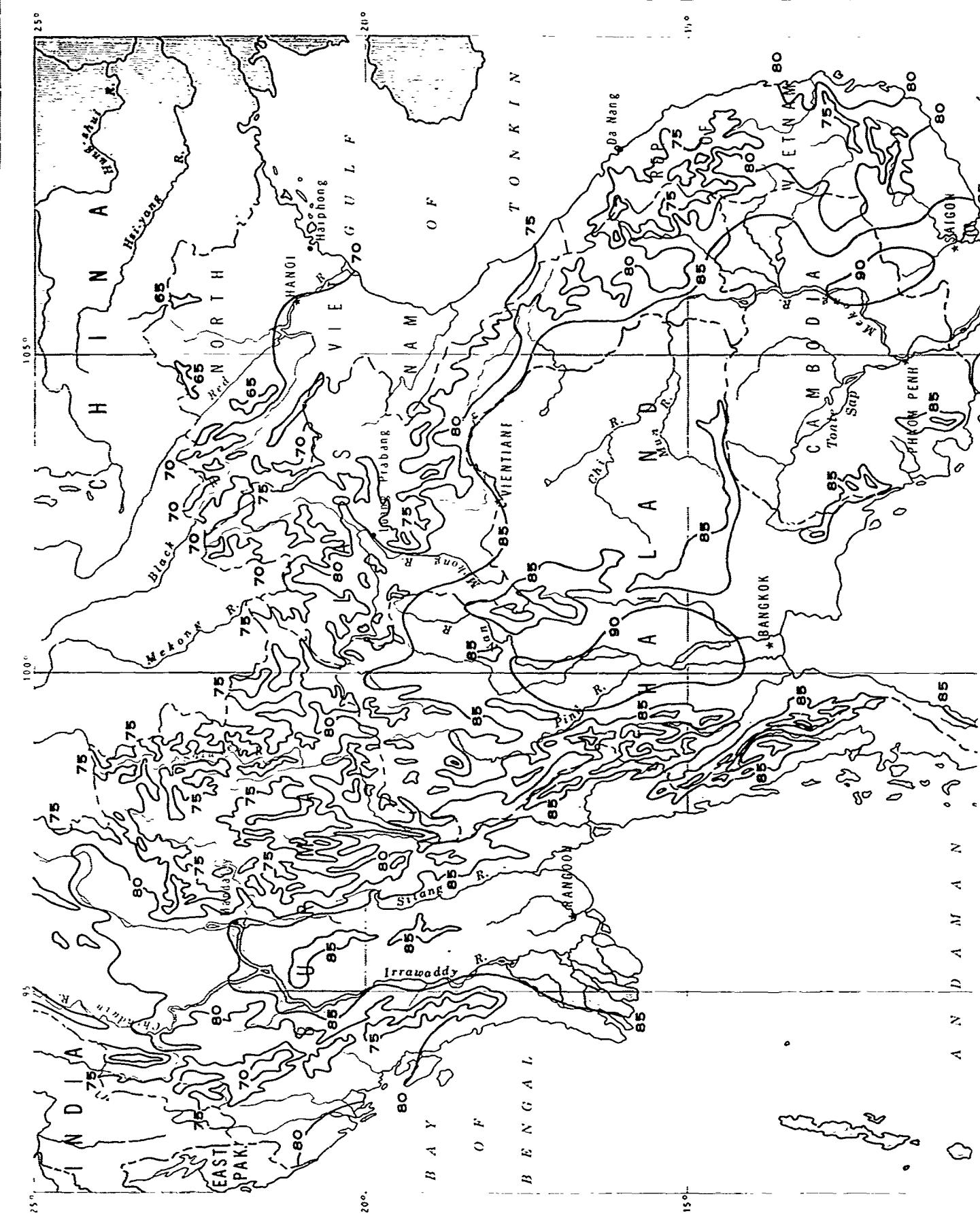
Area of Analogy

50 25 0 50 100
Statute Miles



MAP 15

ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA



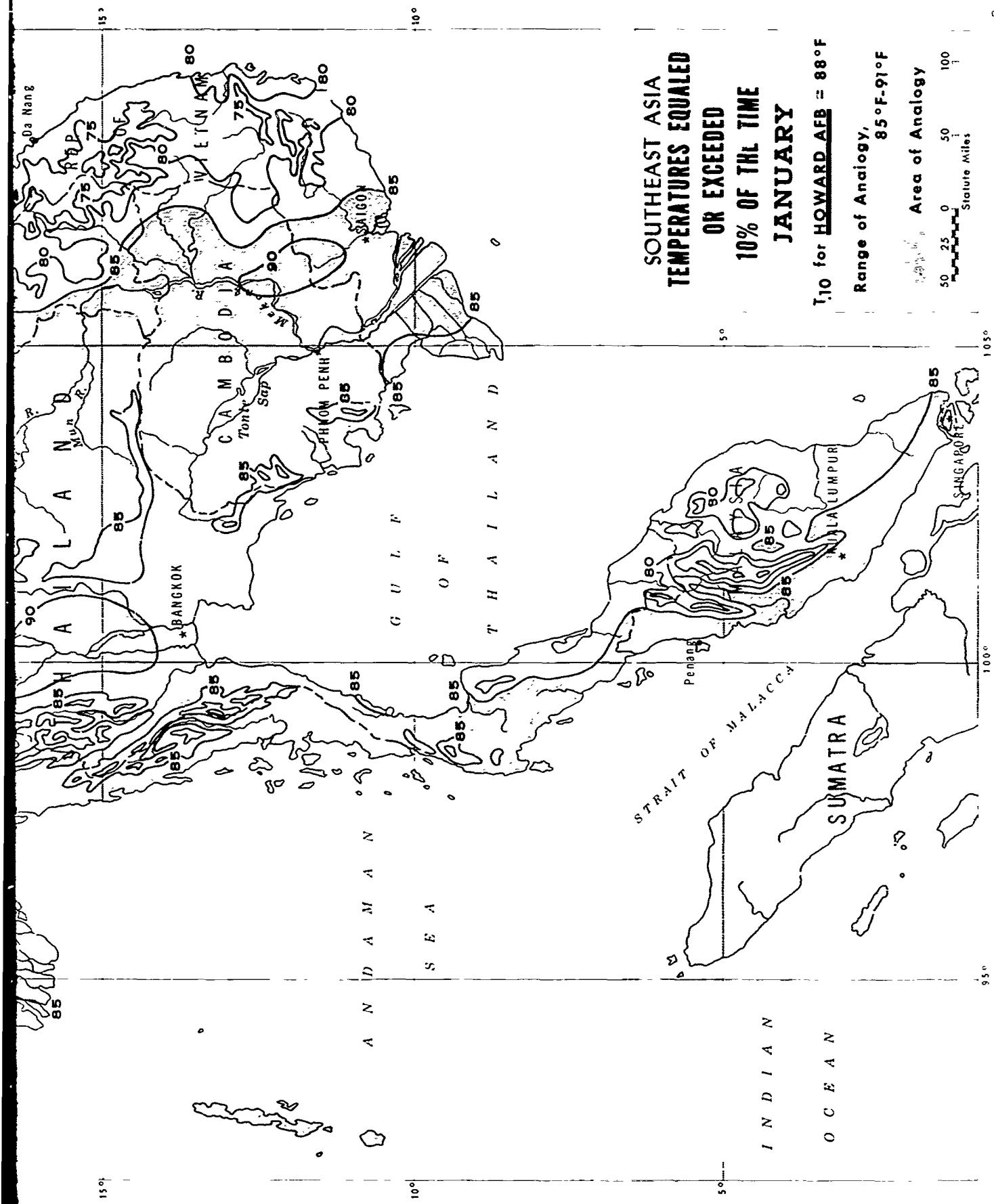
MAP 16

**SOUTHEAST ASIA
TEMPERATURES EQUALLED
OR EXCEEDED
10% OF THE TIME
JANUARY**

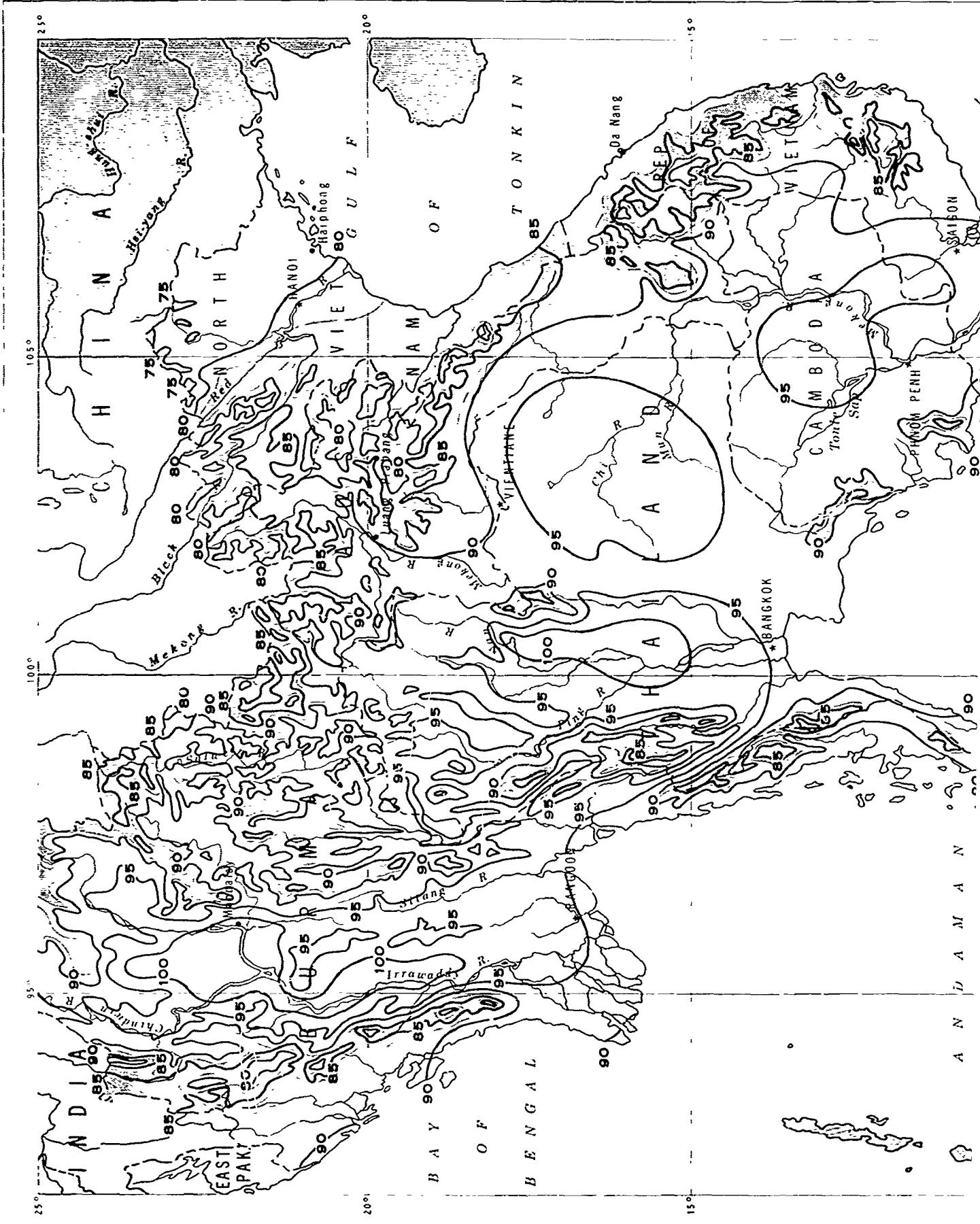
T.10 for HOWARD AFB = 88°F

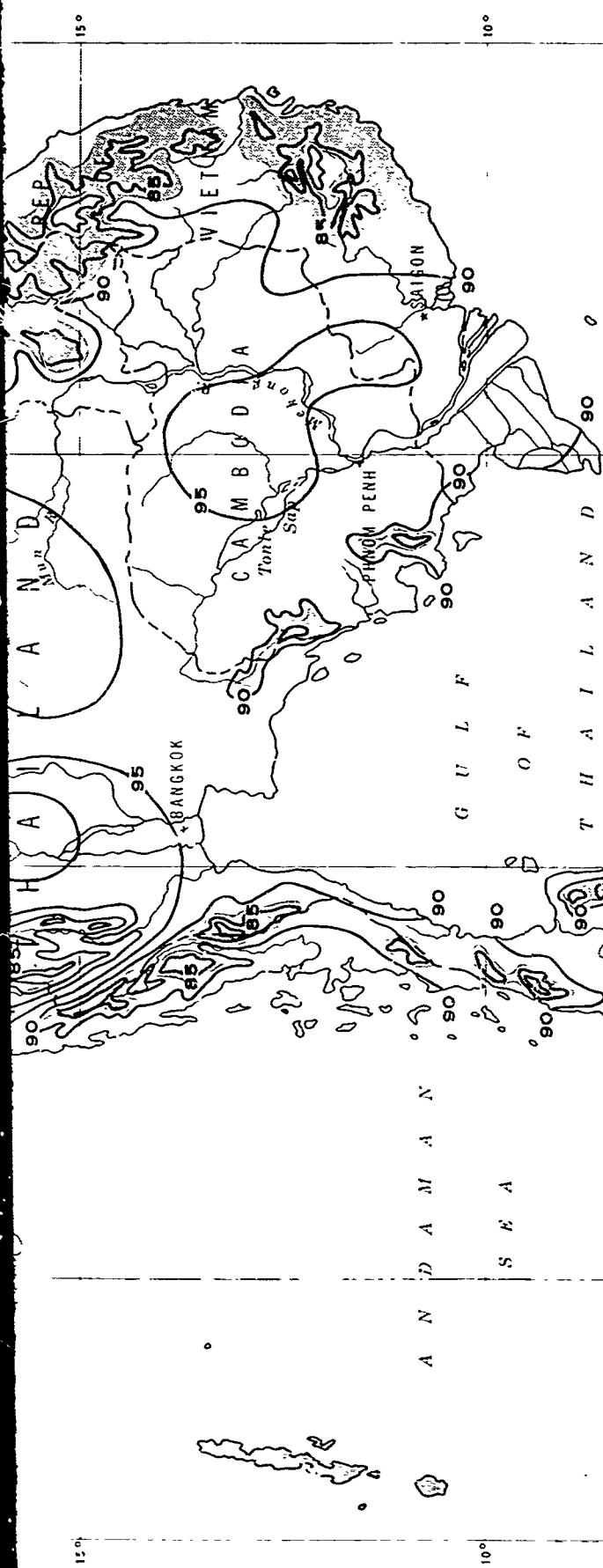
Range of Analogy,
85°F-91°F

Area of Analogy
Statute Miles



ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA





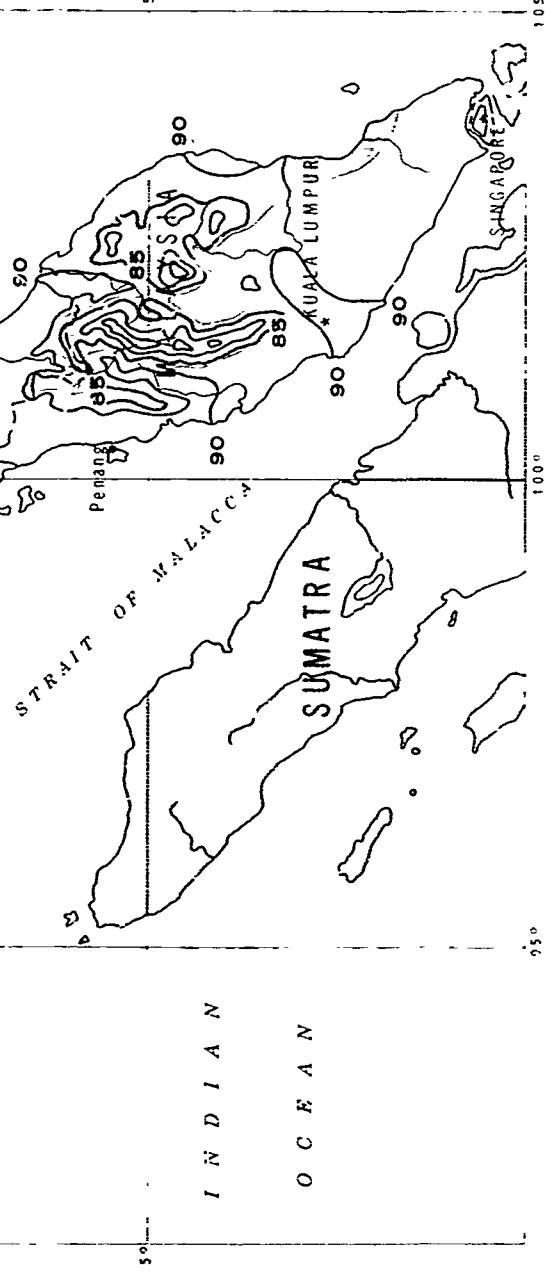
SOUTHEAST ASIA
TEMPERATURES EQUALLED
OR EXCEEDED
10% OF THE TIME

APRIL

T_{10} for CRISTOBAL = 85° F

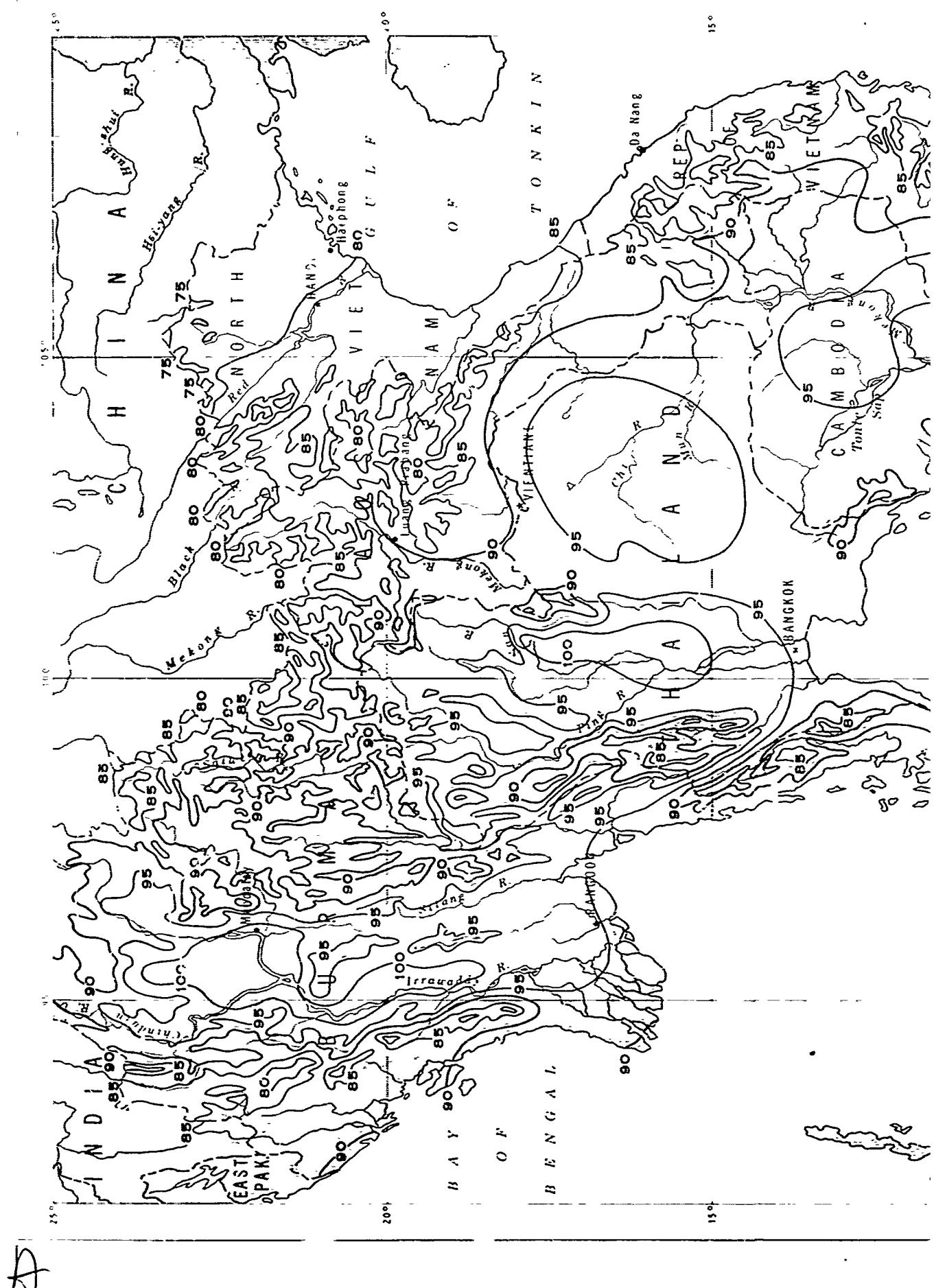
Range of Analogy,
82° F-88° F

Area of Analogy
Statute Miles
0 25 50 75 100



68

ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA



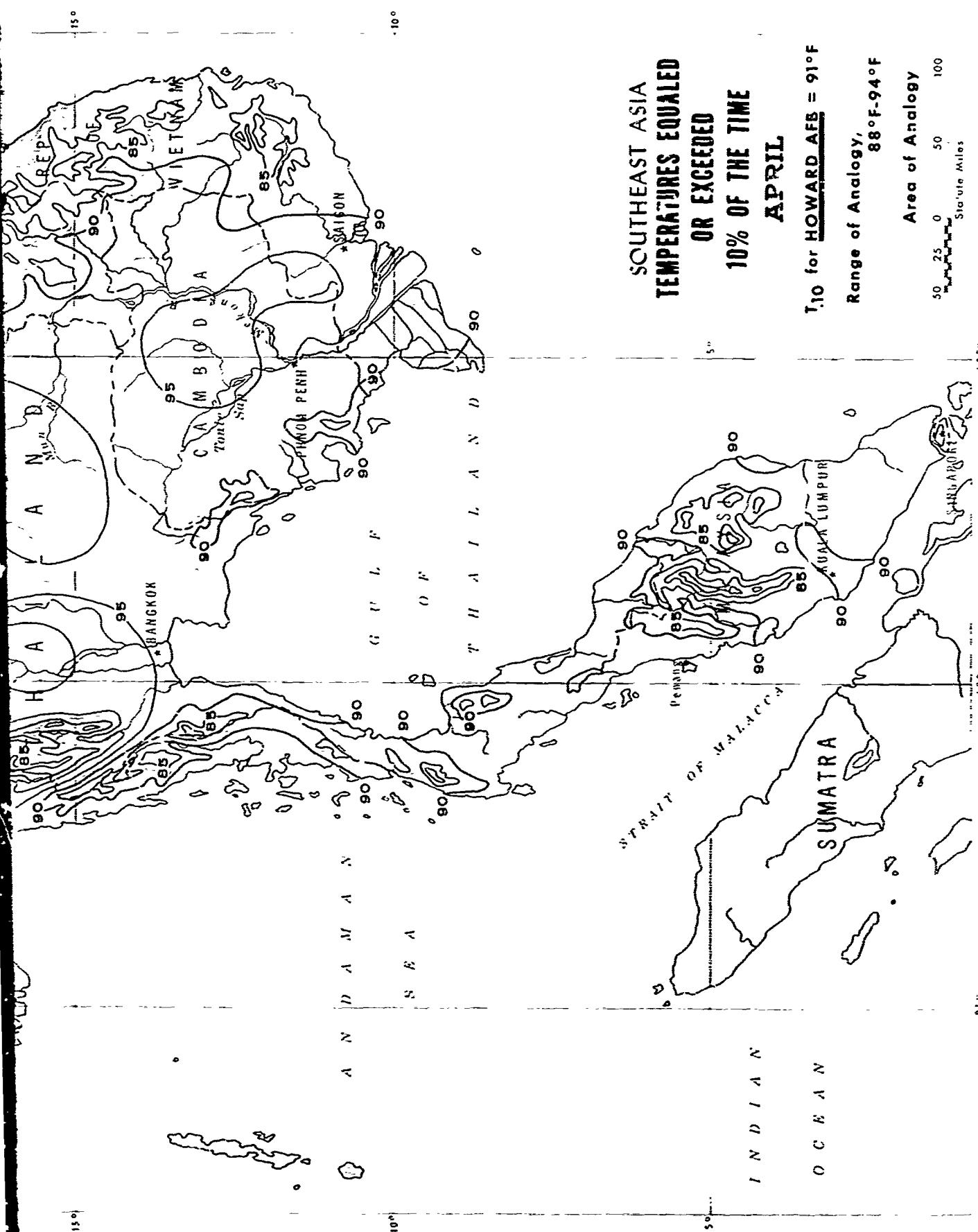
MAP 18

SOUTHEAST ASIA
TEMPERATURES EQUALLED
OR EXCEEDED
10% OF THE TIME
APRIL

T₁₀ for HOWARD AFB = 91°F

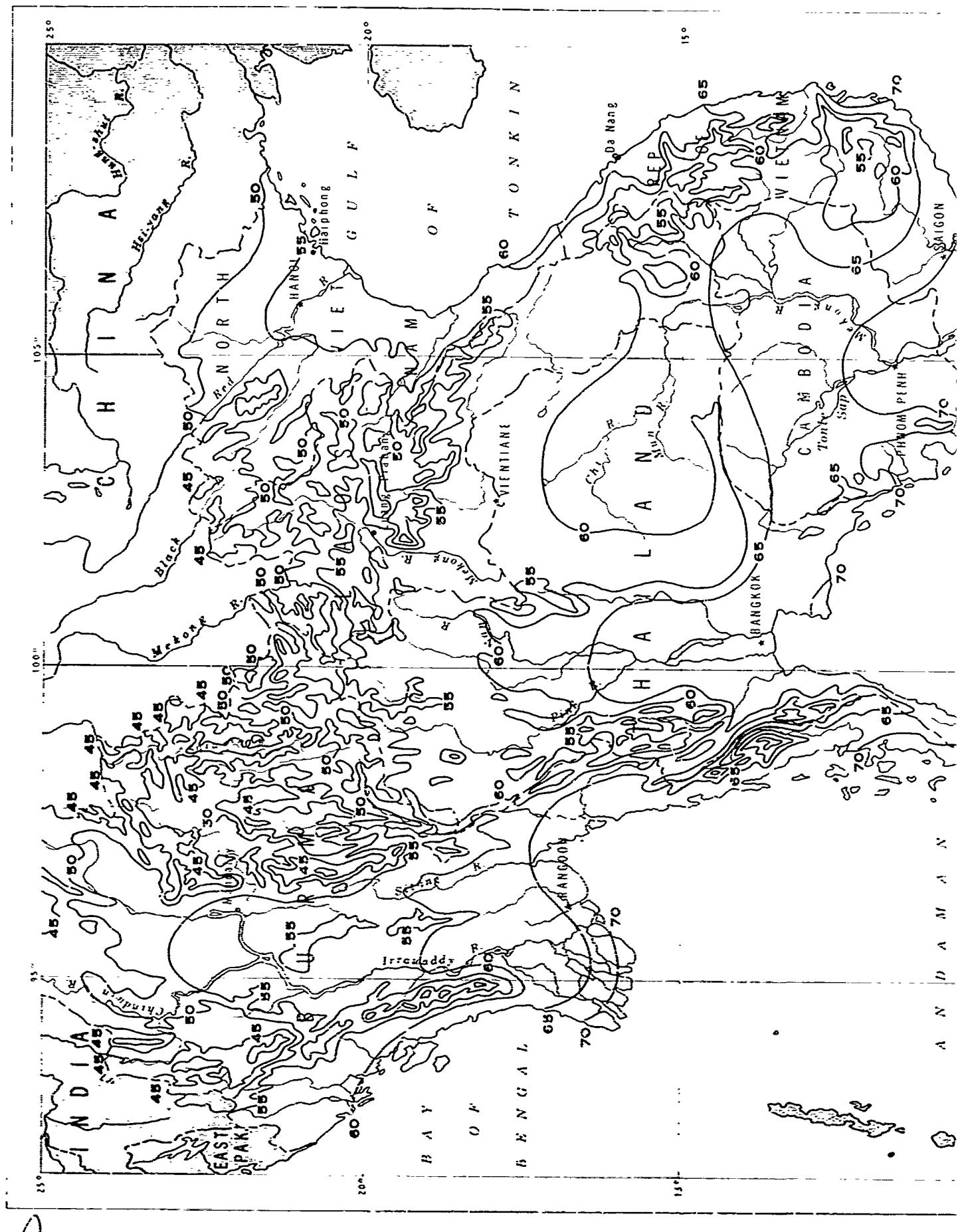
Range of Analogy,
88°F-94°F

Area of Analogy
50 25 0 50 50 100
Statute Miles

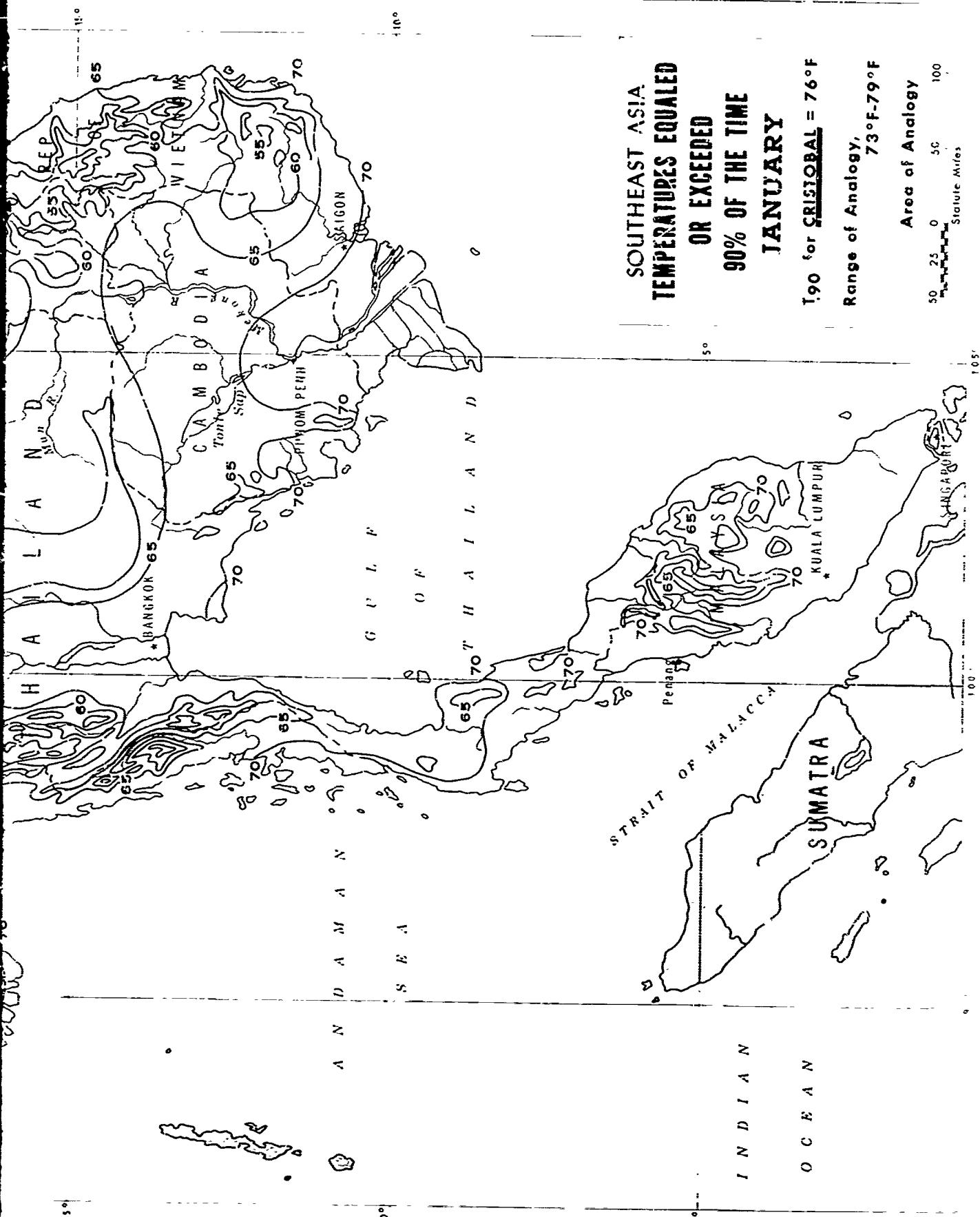


(B)

ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA

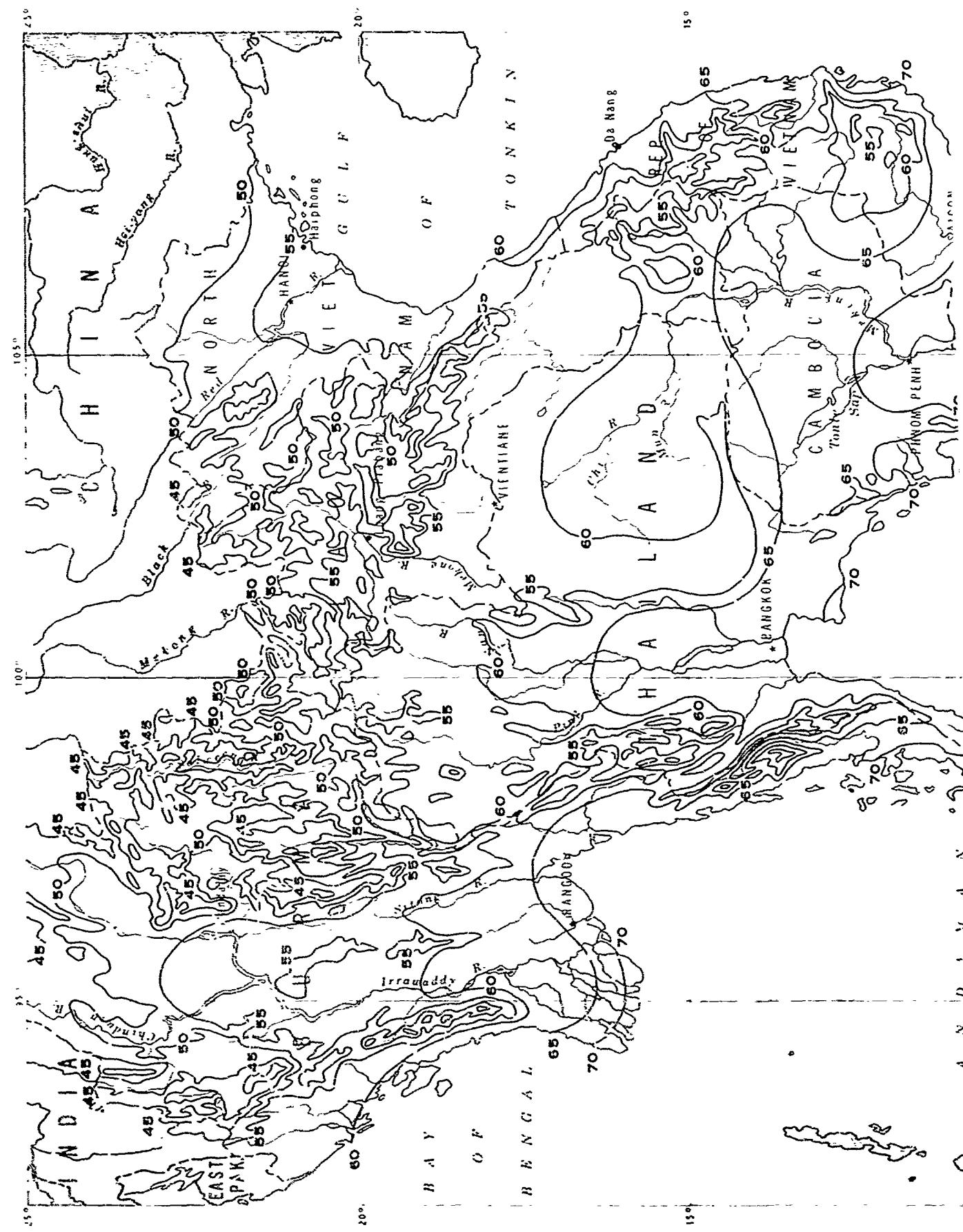


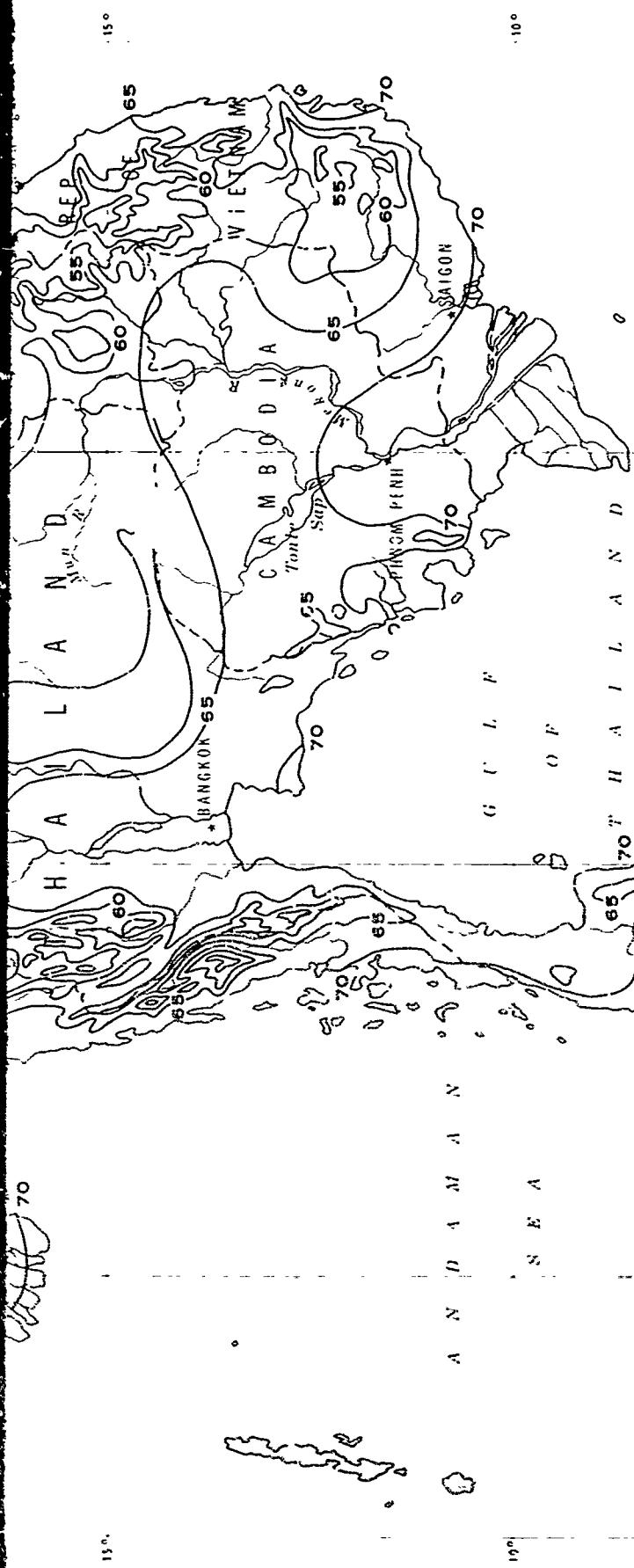
MAP 19



B

ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA





**SOUTHEAST ASIA
TEMPERATURES EQUALLED
OR EXCEEDED**

90% OF THE TIME

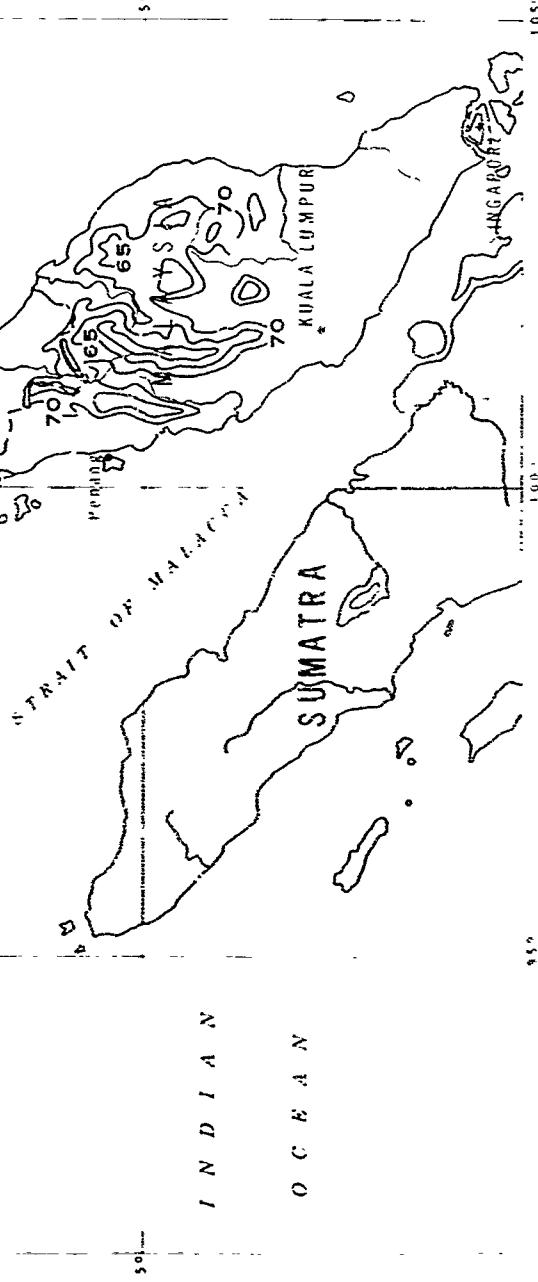
JANUARY

196 for HOWARD AFB = 75°F

Range of Analogy,
72°F-78°F

Area of Analogy

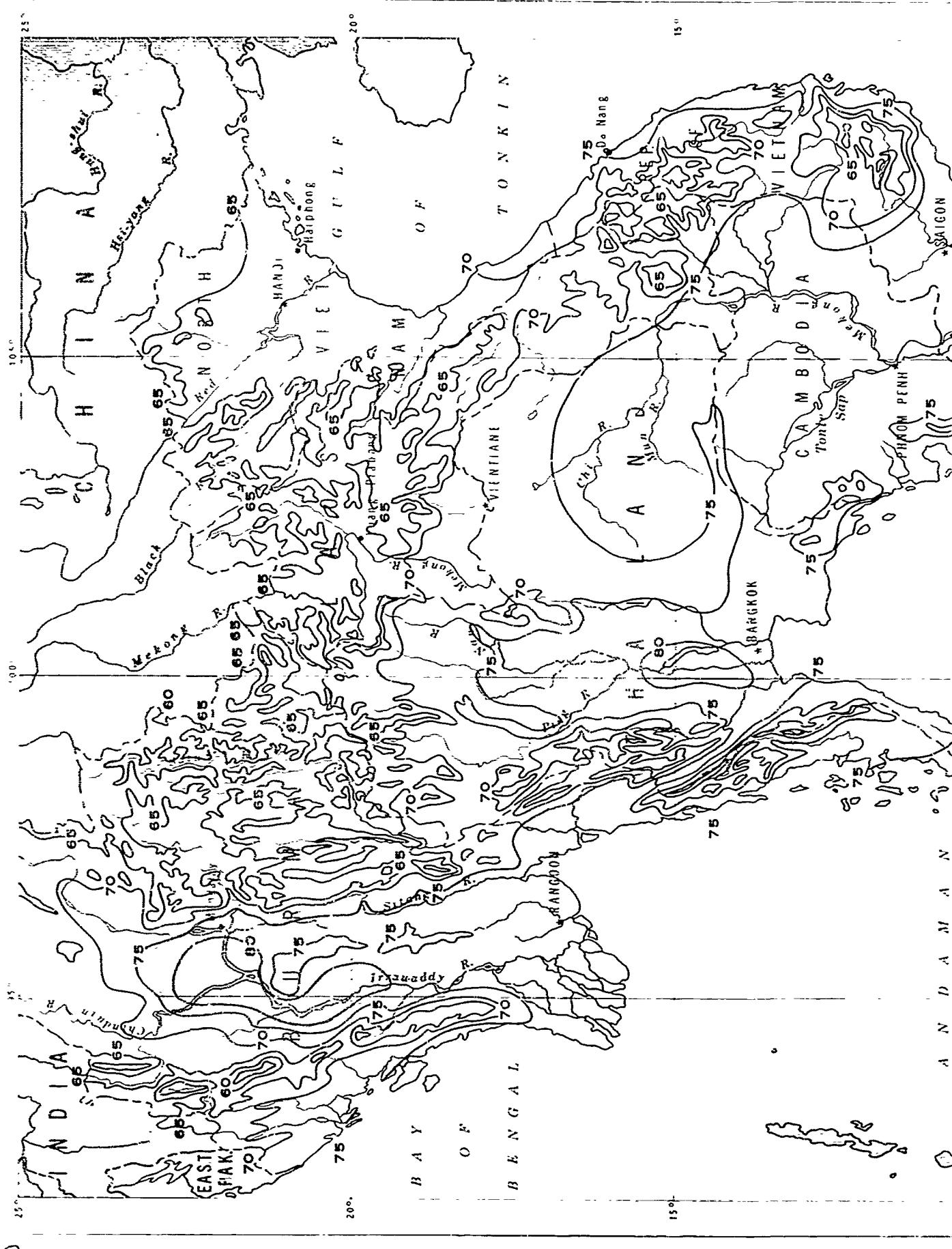
50 25 0 50 100
Statute Miles



MAP 20

(B)

ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA



MAP 21

SOUTHEAST ASIA
TEMPERATURES EQUALLED
OR EXCEEDED
90% OF THE TIME
APRIL

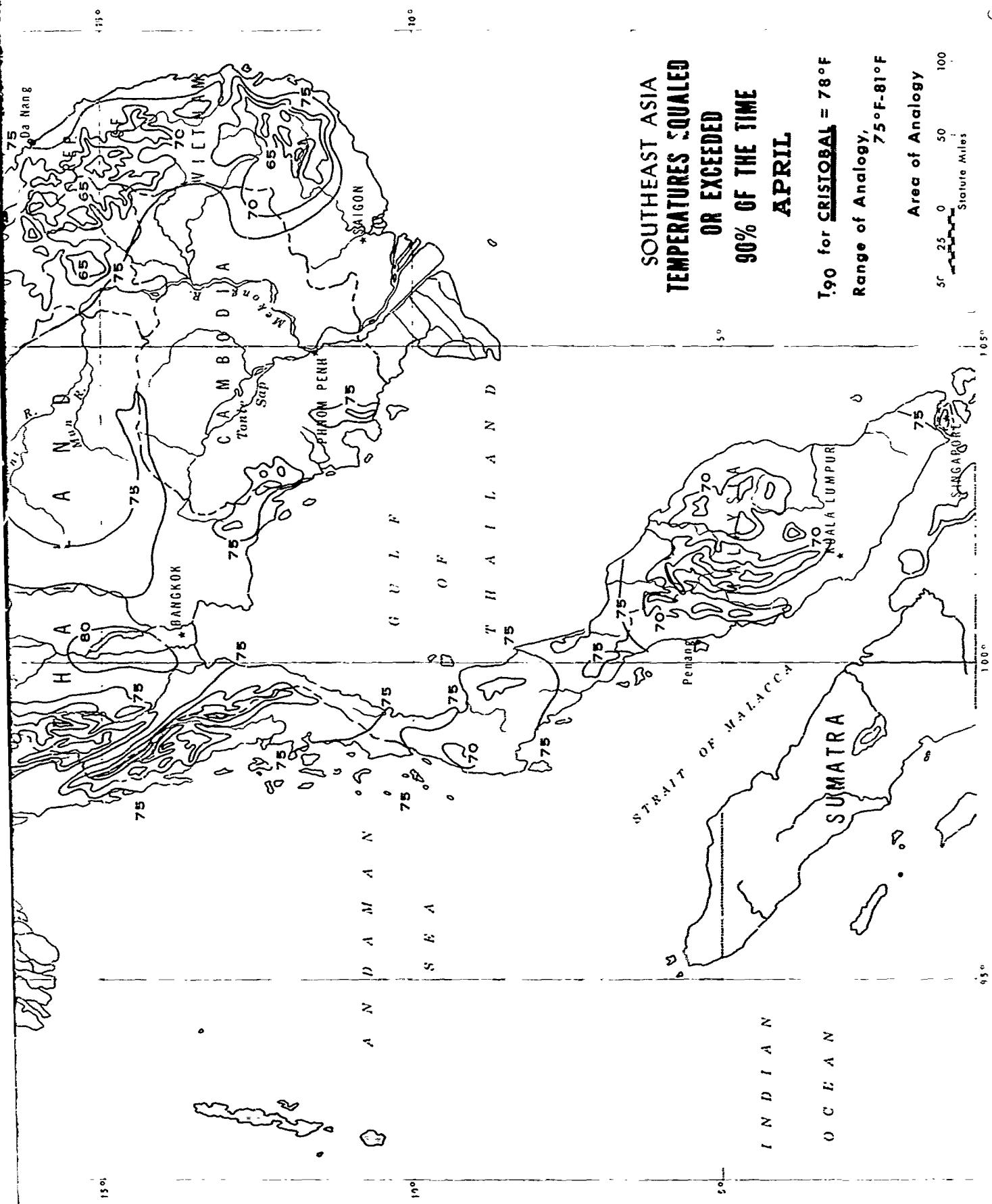
190 for CRISTOBAL = 78°F

Range of Analogy,
75°F-81°F

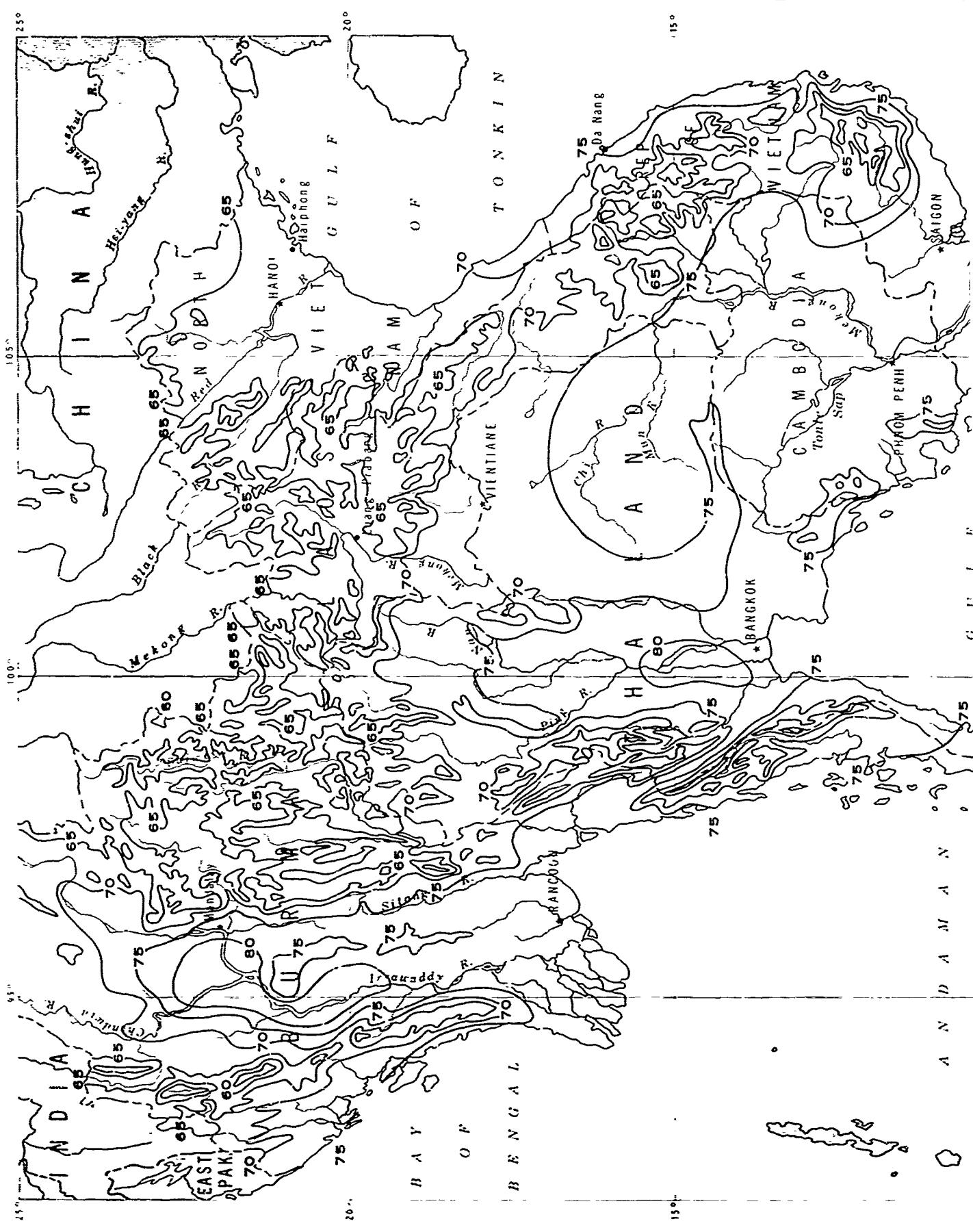
Area of Analogy

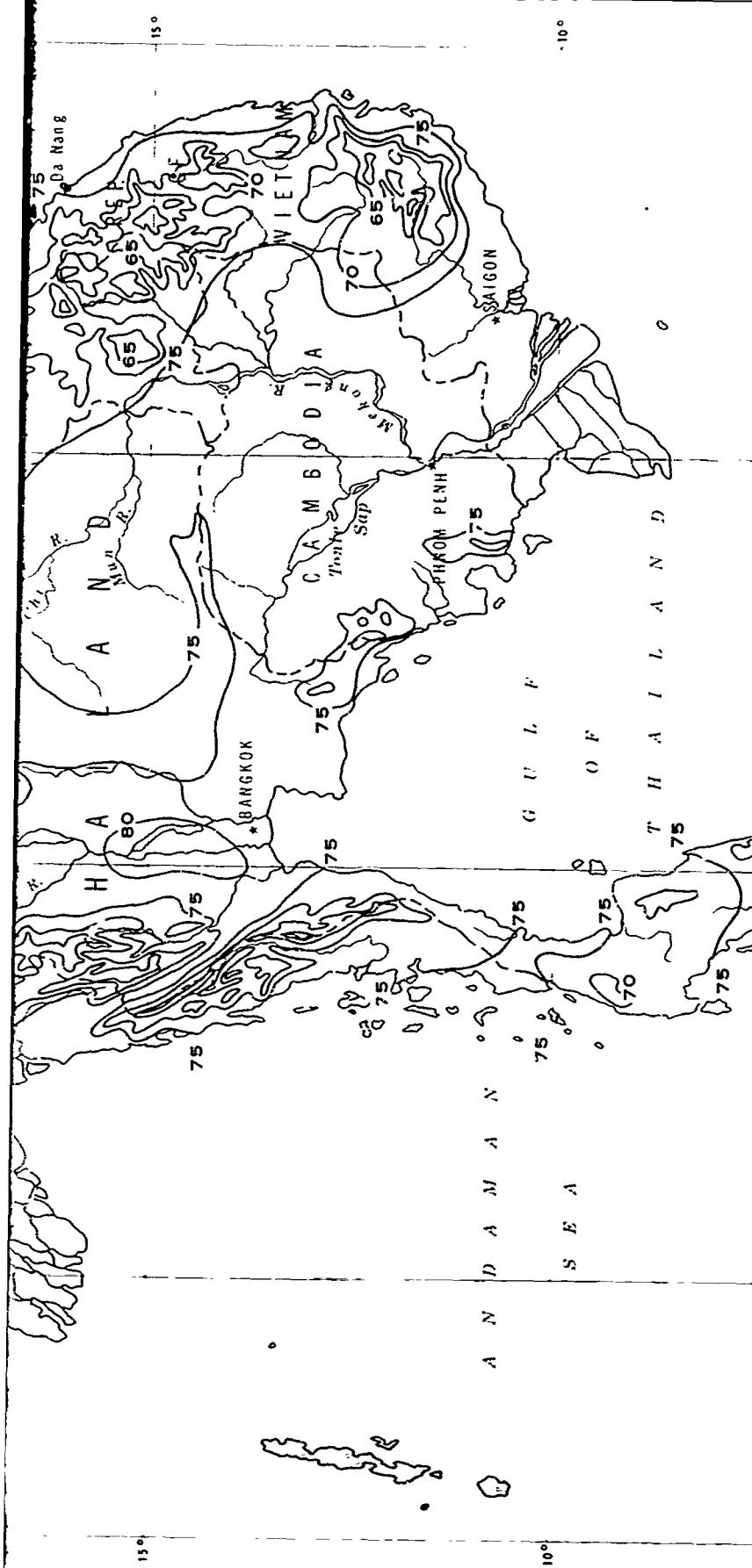
50 25 0 50 100
Statute Miles

(3)



ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA





SOUTHEAST ASIA
TEMPERATURES EQUALLED
OR EXCEEDED

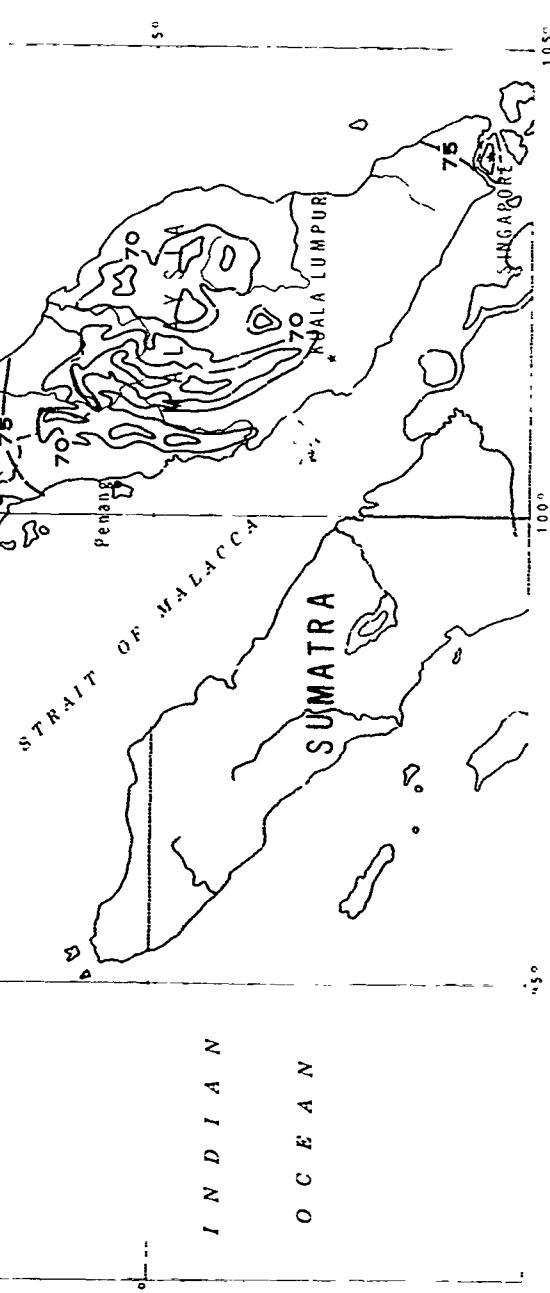
90% OF THE TIME
APRIL

190 for HOWARD AFB = 77°F

Range of Analogy,
74°F-80°F

Area of Analogy

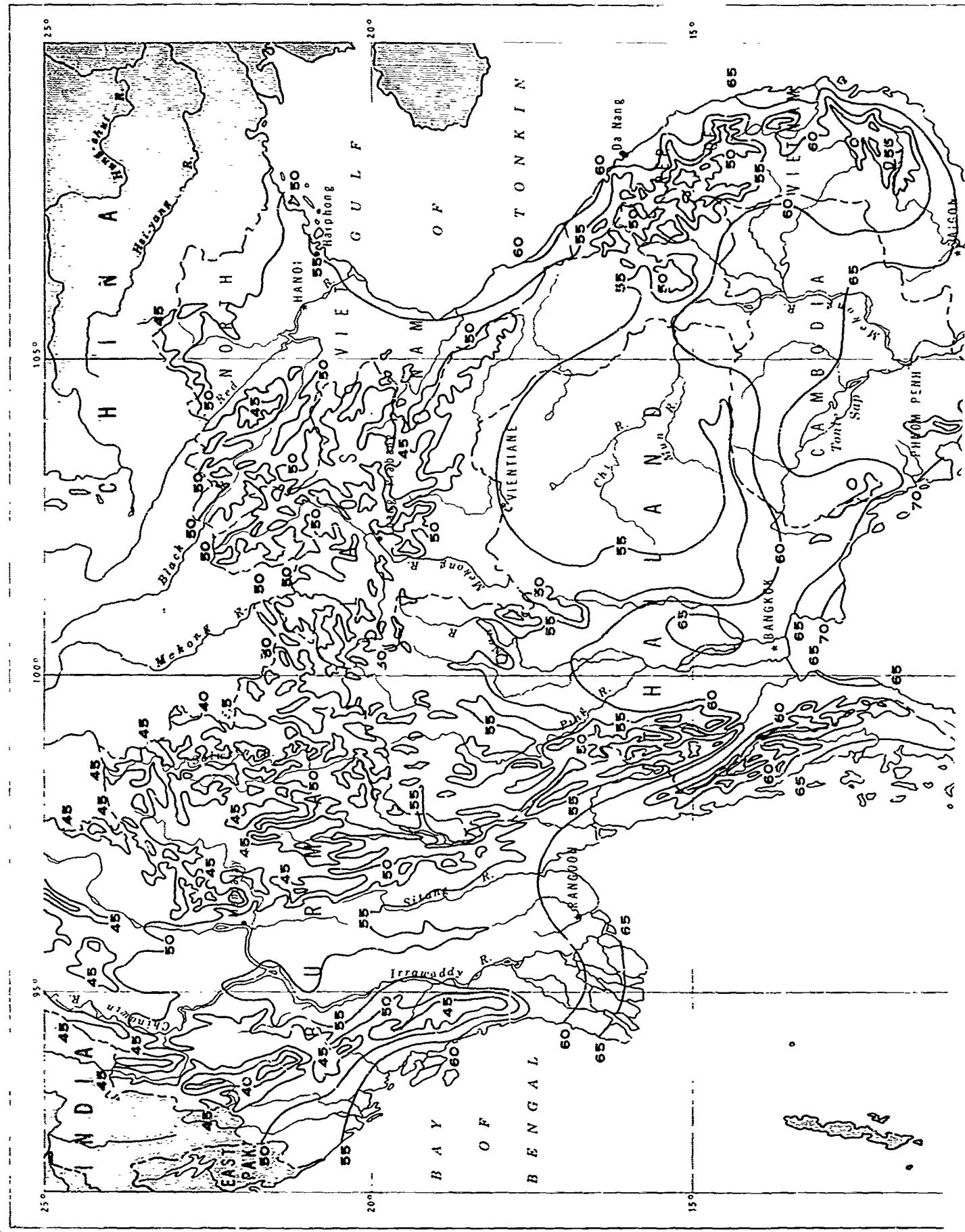
50 25 0 50 100
Statute Miles



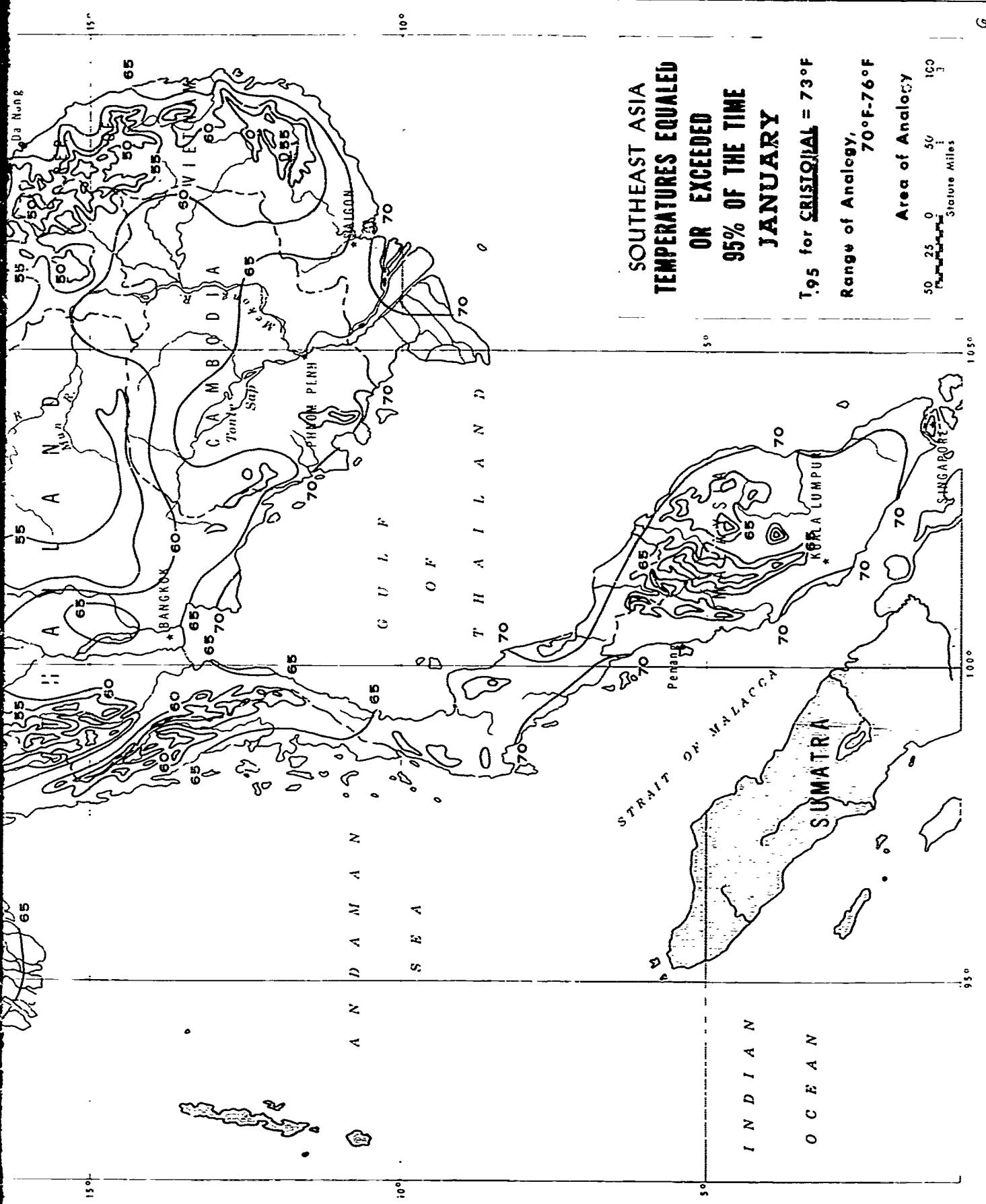
INDIAN
OCEAN

(2)

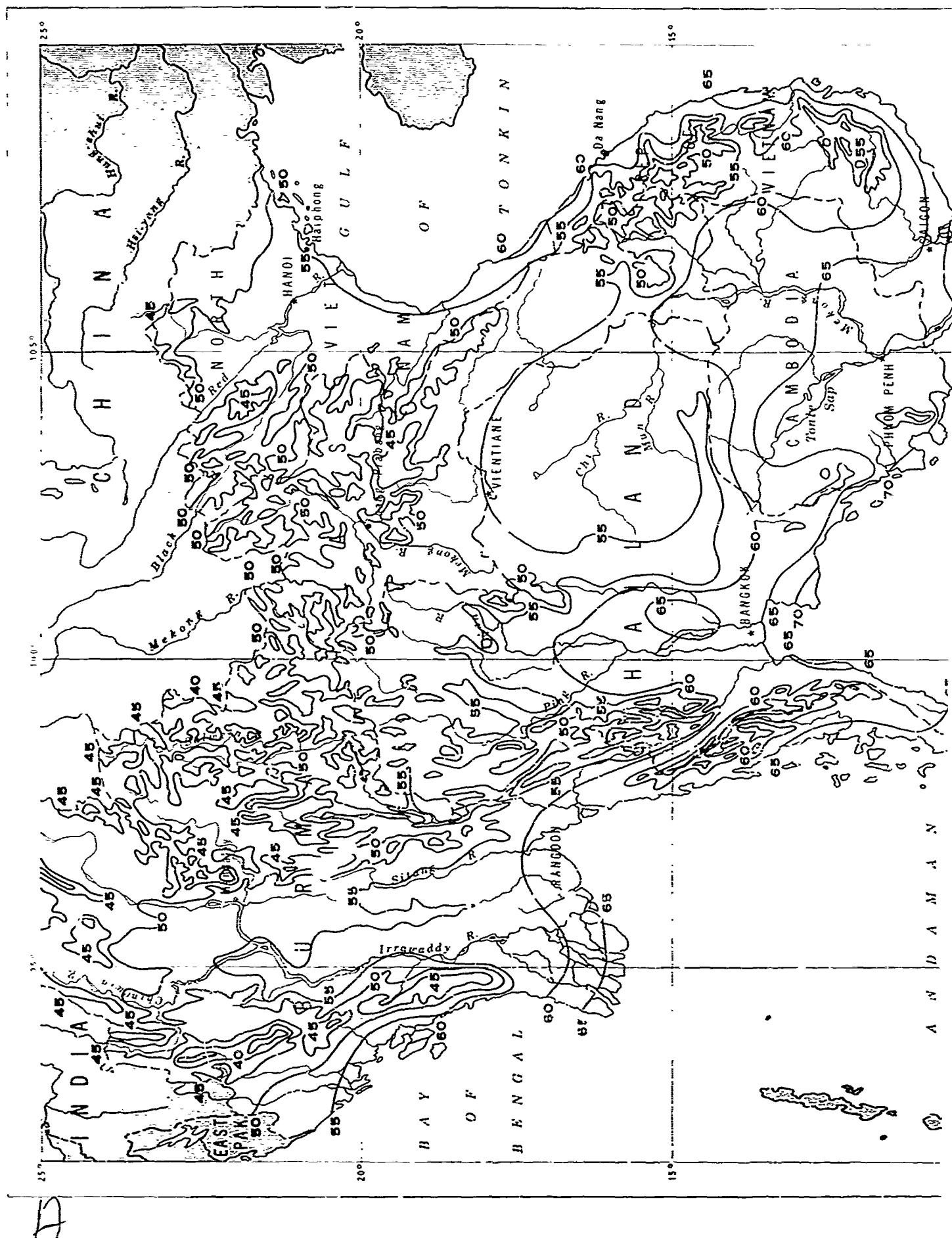
ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA



MAP 2.3



ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA



MAP 24

SOUTHEAST ASIA
TEMPERATURES EQUALLED
OR EXCEEDED

95% OF THE TIME

JANUARY

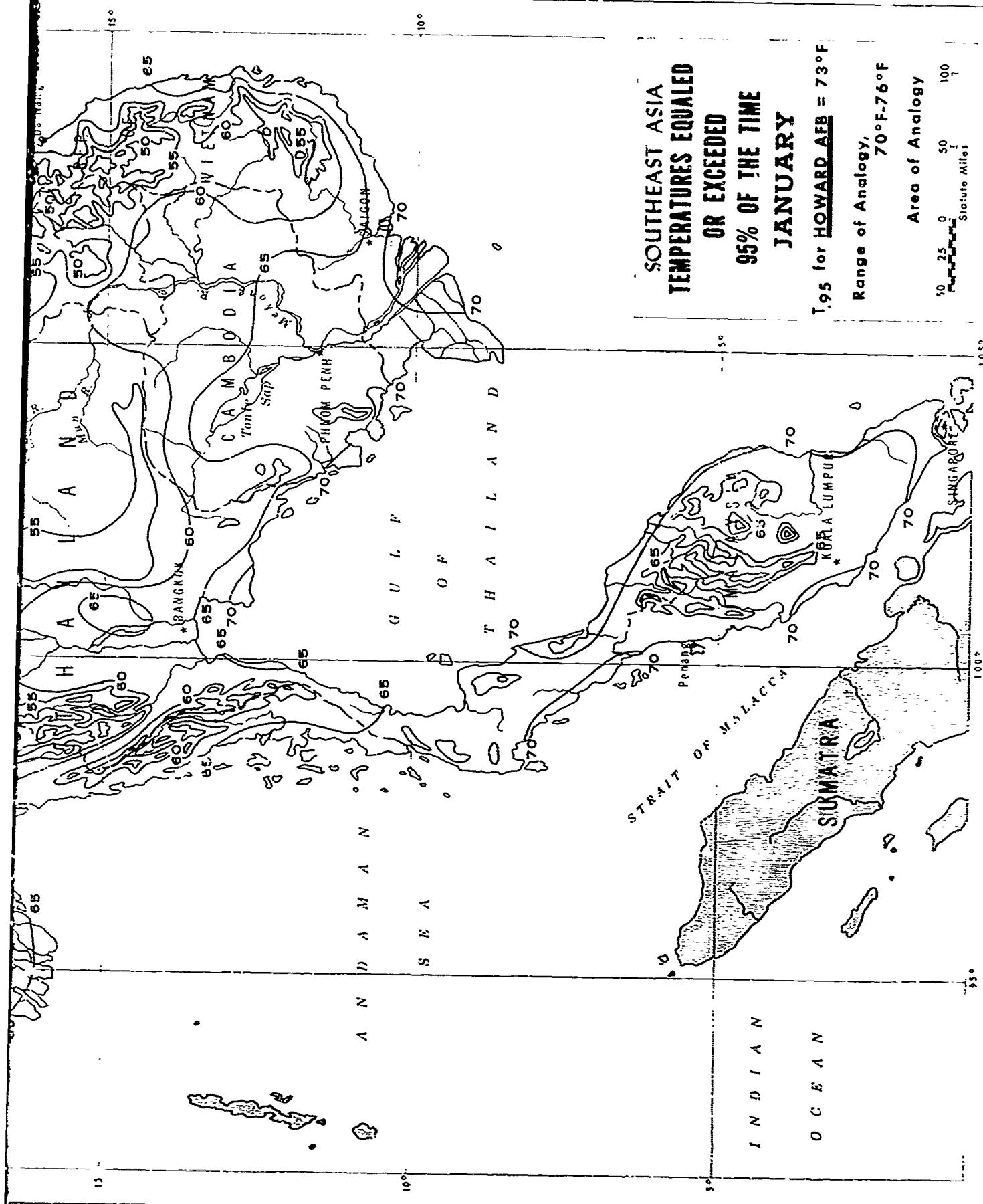
1.95 for HOWARD AFB = 73°F

Range of Analogy,
70°F-76°F

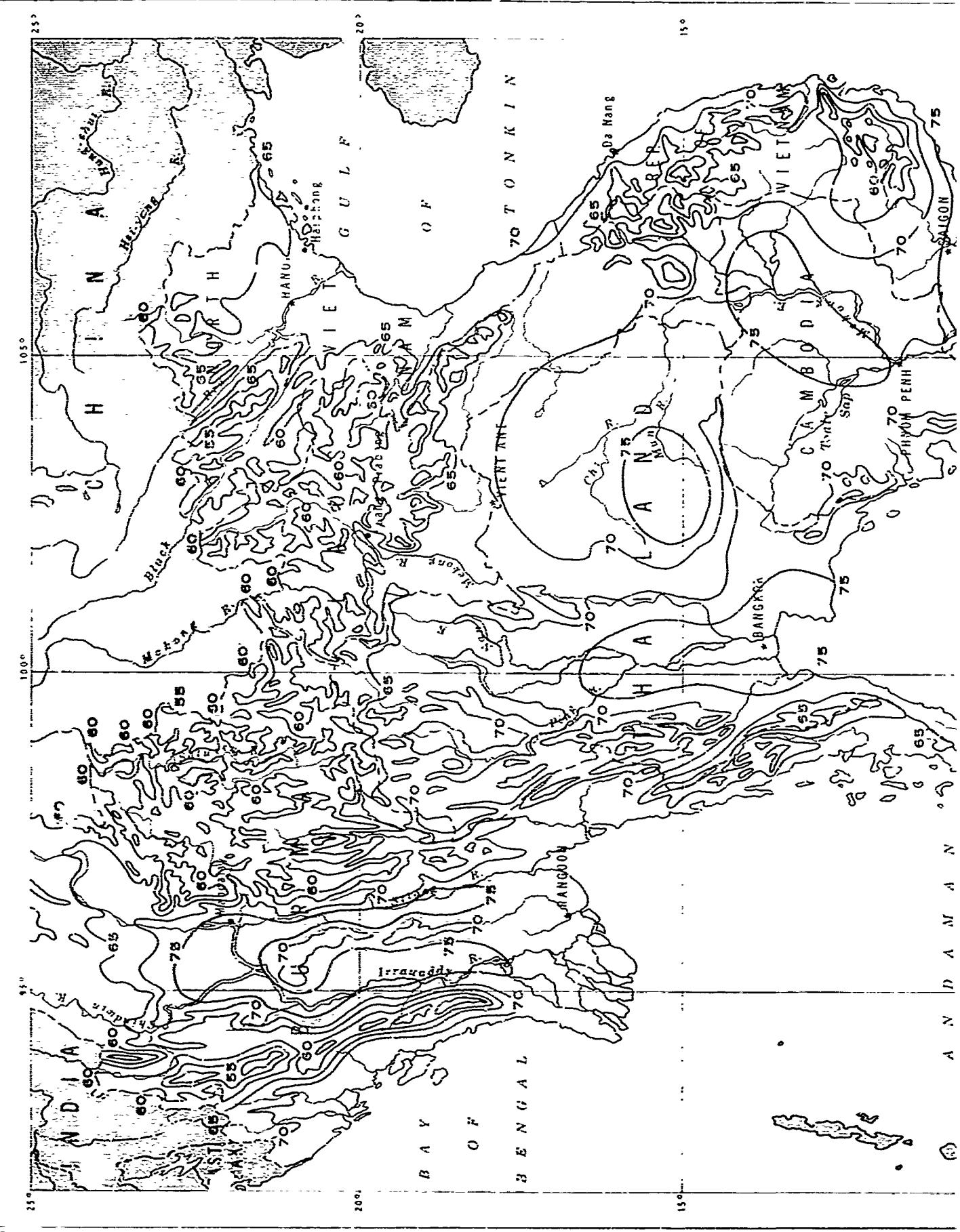
Area of Analogy

70°-76°F
Statute Miles

9



ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA



MAP 25

SOUTHEAST ASIA
TEMPERATURES EQUALLED
OR EXCEEDED
95% OF THE TIME

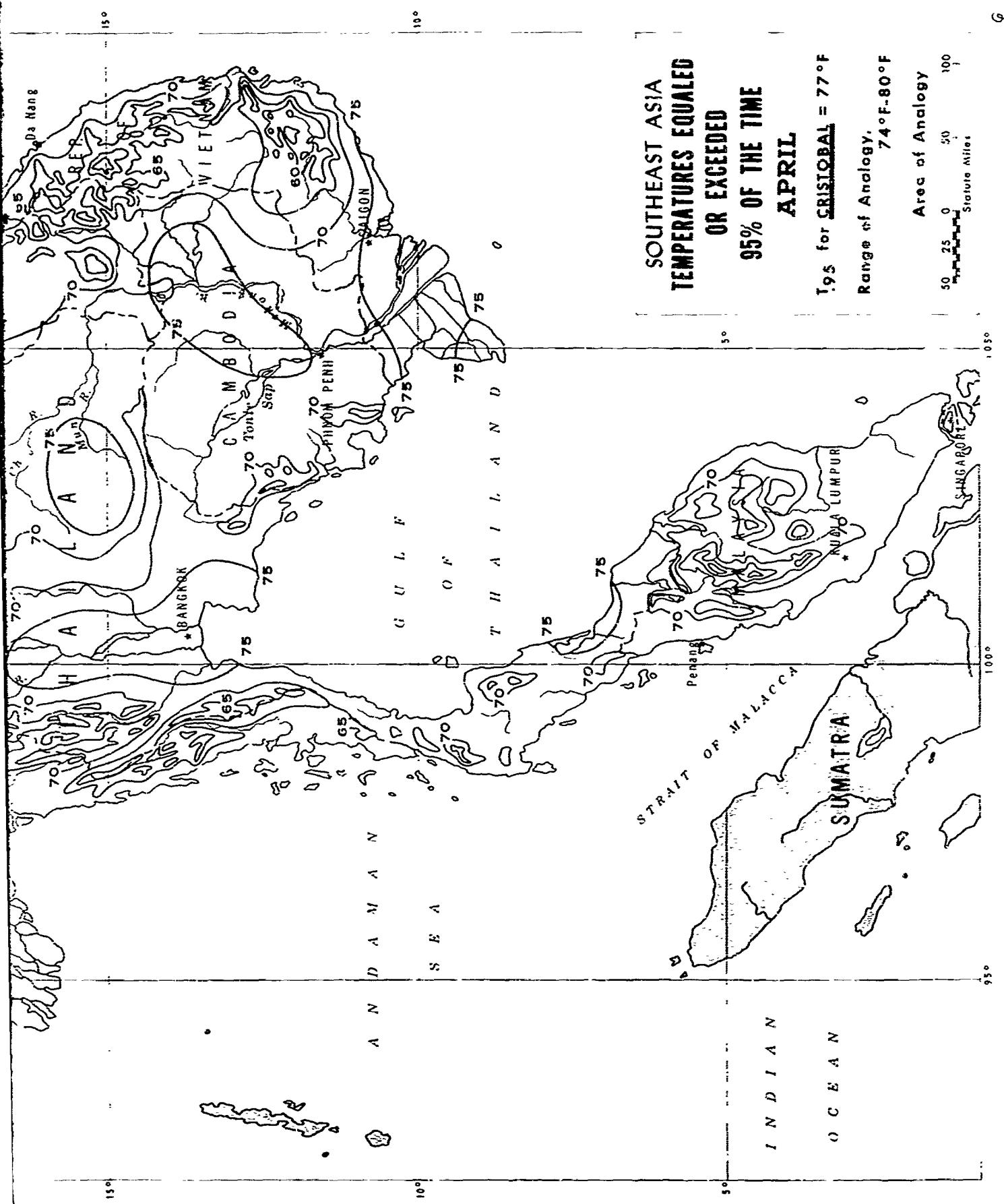
APRIL

195 for CRISLOBAL = 77°F

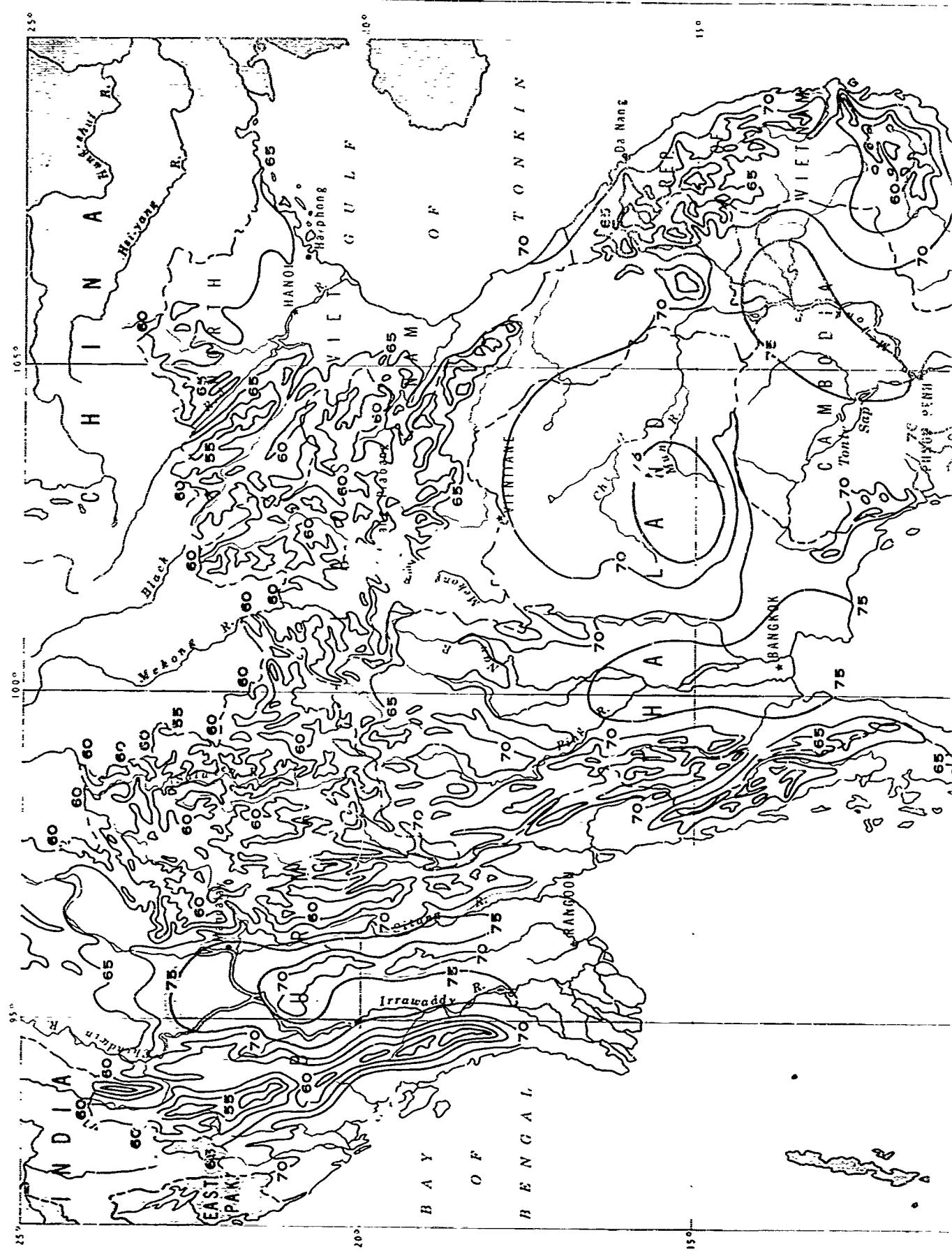
Range of Analogy,
 $74^{\circ}\text{F}-80^{\circ}\text{F}$

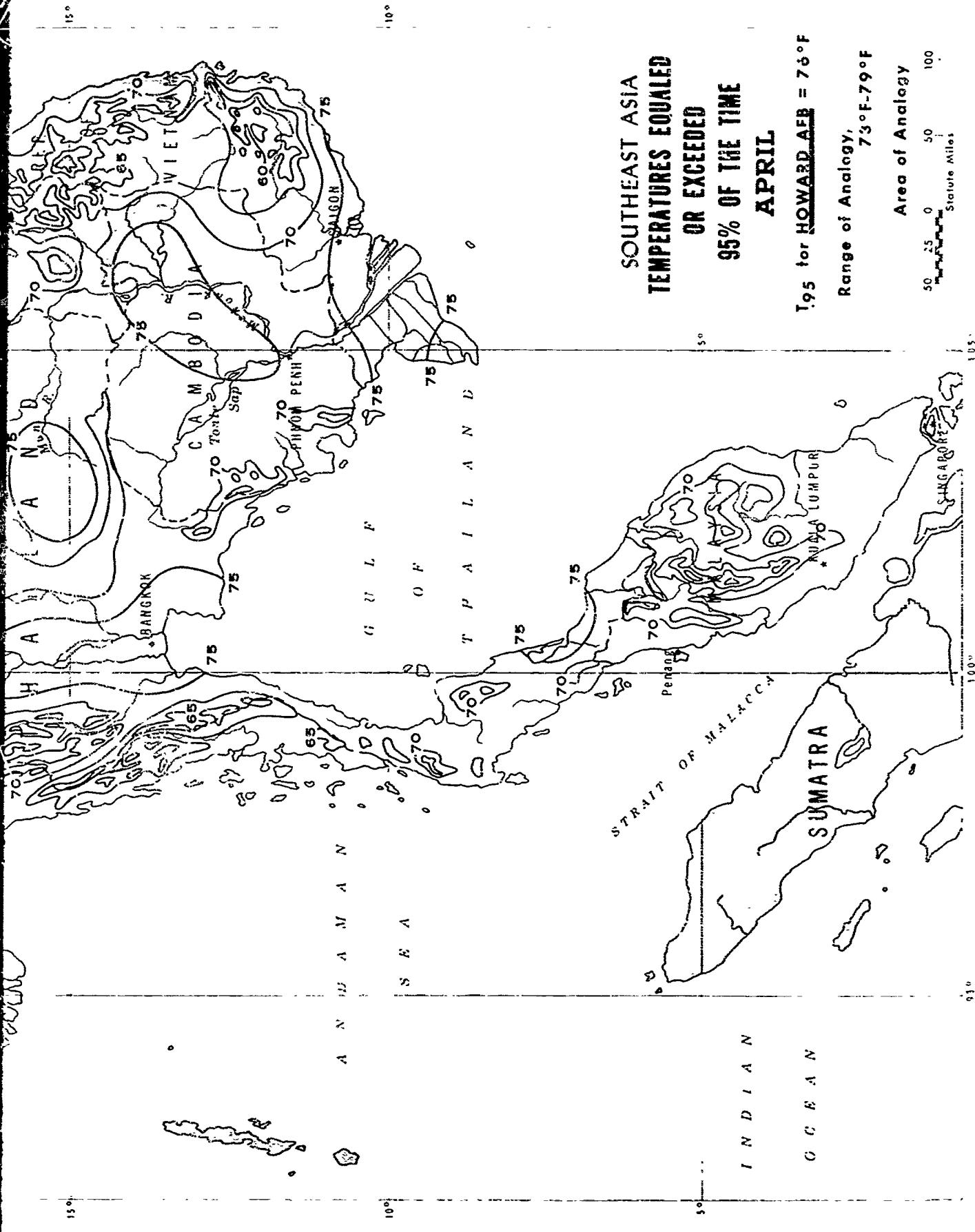
Area of Analogy
Statute Miles

5



ANALOGS OF CANAL ZONE TEMPERATURES IN SOUTHEAST ASIA





MAP 26